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Final report

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1 Acknowledgments

The project team thanks ACIAR for providing financial support and guidance for this project. Special thanks go to PNG's National Agricultural Research Institute, NARI, for their assistance in running this project under sometimes very challenging conditions. It is also important to express our sincere thanks to the farmers of the PNG Highlands who not only accepted our presence but embraced working with us on new idea to keep their soils productive. Tenkyu tru PNG!

2 Executive summary

The July 2014 estimate of PNGs population is just over 6.5 million with about half residing in the Highlands provinces. With population growth at 2-3% per annum and little or no expansion of the area under agricultural production in the Highlands, the pressure on the land resource has resulted in land use intensification via shortening of the fallow phase between cropping cycles. The majority of land users are subsistence farmers who do not use mineral fertiliser to maintain soil fertility. Consequently, unprecedented pressure is being placed on the land resource to increase productivity of sweetpotato (SP), the main staple, to support the burgeoning population. The overall aim of this project was to improve the livelihoods and food security of Highland farmers in PNG by helping them to increase the productivity and longevity of their sweetpotato-based cropping systems. Specific objectives of the project were to evaluate current fallow management practices and the resultant nutritional value of SP crops via an exploratory survey, to identify factors limiting crop yield and evaluate improved nutrient management options, and to test and out-scale best-bet systems for maintaining soil fertility. The work was done in collaboration with NARI in PNG, providing capacity building support to this organization.

The initial exploratory survey conducted in late 2007 showed that cropping cycles in the Eastern Highlands Province, Simbu and Jiwaka were short (1-2 crops over 1-2 years) followed by a short fallow (3 months to 1 year). These short fallows were bush fallows, primarily voluntary grasses, and there were no planted fallows or biomass burning. No mineral fertiliser was used in the SP systems and slash-and-carry of biomass to improve or maintain soil fertility was not practised. Amongst the commonly grown SP varieties average starch content was just under 60% and did not vary significantly between varieties. The same was true for in-vitro starch and K digestibility. However, in terms of human nutrition value, digestibility is governed more by method of food preparation. Sweetpotato starch content tended to be higher in soils with high total N and plant available S. These exploratory results confirmed that focus should be given to within-garden soil management practises that improve nutrient use efficiency through reducing nutrient losses. Although soil fertility appeared to have some impact on tuber nutritional value, it was not possible to pursue this further in this project.

Three sites (Humept in Aiyura, Aquept in Simbu and Aquist in Tambul.) were selected to test soil management practise in relation to soil fertility. Nutrient omission trials conducted on these soils showed that S and N were most limiting to biomass production, followed by Mo and P. There was a strong indication that Nickel was limiting to biomass production in two of the three soil types. These potential micro-nutrient deficiencies, and in particular Mo deficiency, should be followed up, given the importance of Mo to peanut - a possible fallow or intercrop in the SP system. Since farmers do not use mineral fertiliser, management of N is probably the highest priority.

Field experiments were started in 2008. They were maintained in Aiyura for 4-years, in Simbu for 2 years and in Tambul for 1 year. The earlier than planned termination on two of the three sites was due to security issues. It was not possible to locate alternative sites. The field experiments investigated a range of factors influencing soil fertility and cropping potential, including the use of small composted mounds, comparisons between mulching and burning, and between back-to-back SP and SP followed by a short bush fallow, the effect of a legume phase (peanut) and the use of raised beds.

Cumulative yields over the duration of the project were highest with back-to-back SP cropping. Even though yields per season were lowest, the cumulative yields were highest over the 4 years in Aiyura, because SP generated yield while other treatments were under fallow. From a farmers perspective this seems the best practise albeit it cannot be sustained indefinitely. Based on plant tissue analysis of tubers, a 10 t/ha SP crop will remove around 18 kg of N, 45 kg of K and 2 kg of S. Replenishment of the N, K and S

supplies in soil are dependent on the amount of fallow biomass and the quality of the fallow species. Leguminous fallow (e.g. Mimosa in Simbu) produced lower crop yields than the grass fallow (May-grass in Aiyura), but both were able to offset nutrient removal. Even biomass returned from a SP crop (fallow) can be sufficient to balance nutrient removal. The only fallow for which biomass accumulation was insufficient was peanut, due to its poor growth (and also to theft). Whilst farmers are interested in peanut, not only as a good source of protein but as a source of N for a subsequent SP crop, it is necessary that the crop achieves sufficiently high yield. This may not be possible in areas which are simply too cold for peanut production; the earlier observation of Mo limitations may also need to be investigated in more detail since alleviation of this deficiency might help to improve peanut yields in some areas. These calculations are based on a 10 t/ha SP crop which is low compared to possible yields of over 50t/ha. It is obvious that nutrient removal of high yielding SP crops will outstrip nutrient accumulation even on a very productive fallow. Practice change towards balancing nutrient removal with nutrient replenishment probably has no other option than using mineral fertiliser or engaging in slash-and-carry of high nutrient biomass to SP gardens. Composted mounds are amongst the best fertility management options. In the field trials they did not out-yield other treatments, but farmers were interested in this practice; i.e. a downsizing of the very large Engan mounds to an adoptable practise outside Enga Province.

Our on-farm farmer managed trials gave clear indication that small composted mounds are able to achieve higher yields than normal mounds on poorer soils. The slash-and-carry of biomass included Tephrosia, Piper and Tithonia. An additional benefit reported by farmers was weevil control due to possible pesticidal properties of some fallow species.

3 Background

Population growth in the PNG Highlands is amongst the highest in the developing world. Exact rates of population growth are unreliable but they are likely to range from 2% to 3% per annum (Bourke, *pers. Comm.*, 2000 PNG Census). Despite the high population growth, the area under agricultural production has remained relatively stable (Bourke 1997, 2001) with concomitant intensification of land use. Reports on changes to the length of fallow periods are variable owing to the tremendous variety of land-use practises. In some parts of the Highlands fallow periods may still exceed 20 years, whilst in others, particularly in the 'composting zone', very little fallowing is done. Overall, the length of fallow periods has significantly decreased as the population has expanded. In the long-term, the increasing population will lead to further shortening of fallows and lengthening of the cropping phases in farming cycles. There is now evidence that soil fertility run-down is impacting on the productivity of the region's main staple crop, sweetpotato (SP); a crop which occupies some 55% to 90% of land under arable agriculture in the PNG Highlands.

A Scoping Study to analyse soil constraints in sweetpotato based cropping systems and a Survey of Highland farmers in 2005/6 (ACIAR Project SMCN/2005/043), confirmed that farmers are well aware of declining SP yields and are concerned about the implications. They attribute the problem to deteriorating soil fertility and to the use of old SP varieties. Comparing yields from gardens recently brought into production after fallowing (i.e. 'new' gardens) with those from gardens about to be fallowed (i.e., 'old' gardens), revealed a 50% (2 to 8 t/ha) reduction in tuber yield by the time fallowing is due (Scoping Study results). However, low soil fertility in the Highlands region is unusual owing to the high concentration of organic matter in soil, i.e. up to 20% organic C may be present with favourable C/N ratios of around 12 (Scoping Study results). However, despite high apparent nutrient stocks in soils, most SP leaf tissue sampled in the Scoping Study had low nutrient levels, in particular low concentrations of N, P, K and B. The N and K levels were particularly low in old gardens, which implied that low tuber yields in old gardens were associated with suboptimal nutrient uptake, despite apparent high nutrient stocks in soil. In a companion project, CP/2004/071, the problem of low SP yields was addressed from SP variety and virus pathogen perspectives. However, it was beyond the scope of this project to evaluate the improved pathogen tested SP varieties at different levels of soil fertility or crop nutrition and under different rainfall and temperature conditions; the latter having a pivotal role in tuber initiation. Sweetpotato varieties with different levels of pathogen resistance therefore need to be evaluated within the context of improved soil fertility management options and under contrasting environmental conditions in order to understand and more fully exploit the potential of this important food production system.

Accordingly, in the present project a dual approach was employed to provide a better understanding of the soil and environmental factors controlling SP production and to help identify practical management options with the potential to prevent declines in SP yield. To this end, process studies were first of all be conducted to fill critical knowledge gaps in water and N dynamics relevant to sweetpotato growth cycles, and then, secondly, complementary adaptive on-farm research was undertaken to identify and test 'best-bet' soil management techniques for maintaining and increasing the productivity of sweetpotato-based cropping systems. In order to be practical and adoptable, the latter best-bet options were developed in partnership with NGOs and farmers. Our primary target group was small-holder producers in the more accessible and densely populated parts of the Highlands who are producing at least some of their crop for small scale commercial marketing, and have capacity to invest limited resources into intensifying production. Underpinning this dual approach was a strong focus on capacity building in soil research and management so that further research and dissemination of soil management techniques may be carried out beyond the life span of the project.

The objectives of the project therefore were:

1. To assess and quantify soil and water processes affecting sweetpotato growth in PNG Highland soils
2. To develop and implement improved nutrient and water management options for sweetpotato-based cropping systems
3. To enhance soil research capacity in PNG

The project team was led by the University of Queensland in collaboration with the Queensland Department of Primary Industries and Fisheries in Australia, and with the National Agriculture Research Institute (NARI) (through its Main Highlands Program), local high schools in three provinces and other collaborating institutions and farmers, in PNG. These collaborative linkages were to ensure a seamless interaction from research organisation to farmer level so that adoption pathways could be realised.

The expected outputs from the project will be enhanced knowledge of key water-nutrient dynamics pertinent to soil management techniques, practical options for improving soil fertility management under different environmental conditions, increased soil research capacity in NARI, and an enhanced capacity for out-scaling soil management techniques to farmers via the collaborating institutes and organisations. The anticipated impact of the project will be increased ability by Highland's farmers to sustainably manage their available land resource, increase the productivity of sweetpotato and associated crops, and improve their livelihoods.

4 Objectives

The aim of this project was to improve the livelihoods and food security of Highland farmers in PNG by increasing productivity of sweetpotato-based cropping systems. This was partly achieved through the following objectives:

4.1 Objective 1: To assess and quantify soil and water processes affecting sweetpotato growth in PNG Highland soils

4.1.1 Rationale:

Despite being subject to high levels of rainfall and having high levels of organic matter and nutrient stocks, soils in the PNG Highlands respond to SP crop demands as if they are nutrient limited. An in-depth understanding of soil (nutrient) and water processes is therefore needed to provide a rational basis from which appropriate soil and nutrient management techniques may be derived and indigenous soil management systems improved.

4.1.2 Activities:

1. Review past published/documented soil/agronomy research relevant to PNG highland soils (link to publications of scoping study results)
2. Conduct and exploratory survey to delineate potential soil fertility management options
3. Establish controlled experiments in 3 sites to monitor key soil, water, erosion, nutrient processes in relation to SP growth cycles/seasons under a range of existing soil management systems
4. Quantify the influence of soil water and nutrient dynamics within different soil management systems on the yield (tubers), physiology and tissue nutrient levels of sweetpotato.
5. Synthesise results with respect to developing on-farm activities in objective 2 and 3 (in collaboration with CP/2004/071, mid project review)
6. Develop soil nutrition information packages and soil and tissue testing protocols for sweetpotato production systems in Australia (targeted component underpinning Australian component of CP/2004/071)

4.2 Objective 2: To develop, implement and evaluate improved nutrient and water management options for sweetpotato-based cropping systems

4.2.1 Rationale:

Farmers consider soil fertility decline, including nutrient losses through erosion, as an important limitation on SP production. Indigenous and improved or alternative soil fertility management systems need to be tested and compared in partnership with farmers and NGOs to ensure adoption of the more sustainable systems. Action learning cycles will be needed which capitalise on low level (farmer's field) as well as high level (on-station) system assessments to further refine 'best-bet' management strategies.

4.2.2 Activities:

1. Develop improved nutrient and water management options in collaboration with farmers and NGOs
2. Implement 'mother' and 'baby' trials to evaluate 'best-bet' management options
3. Evaluate/fine tune via a continuous improvement cycle
4. Develop adoption pathways through knowledge sharing with other agencies to ensure wider dissemination of research outputs and out-scaling of technologies

4.3 Objective 3: To enhance soil research capacity in PNG

4.3.1 Rationale:

Continuation of the action learning cycle beyond the life of the project depends on training of national staff in soil science and provision of fundamental equipment. As the development of human resources and scientific capabilities in PNG's Universities and educational institutions is not producing sufficient skilled agricultural and soil researchers, a high priority is assigned to the development of human resources in NARI. One of the key issues in this area is matching NARI's expertise profile with the identified R&D priorities by providing further training and career development.

4.3.2 Activities:

1. Support relevant training of NARI laboratory personnel at Kila Kila and Aiyura
2. Develop basic lab facilities in Aiyura and train local technicians
3. Build capacity and technical ability of locally engaged high schools, other organisations and innovative farmer groups
4. Targeted training in new soil science methodology relevant to project

5 Methodology

5.1 Objective 1: To assess and quantify soil and water processes affecting SP growth in PNG Highland soils

We selected 3 regions to assess and quantify soil water and nutrient budgets linked to soil management practises most relevant to each region: (i) Aiyura site < 1700 m.a.s.l. (ii) Kundiawa 1700-2400 m.a.s.l. and (iii) Tambul > 2400 m.a.s.l. Soil fertility management techniques imposed at selected locations were: (i) Composted mounds; (ii) Short natural fallows or improved fallow (4-12months); and (iii) Legume rotations (Note: composted mounds were used at all locations). During the cropping cycle the following variables were monitored: (i) climate (rainfall, ET, T, RH); (ii) growth of sweetpotato and other crops, including legumes; (iii) soil water content using FDR and tensiometers and soil temperature; (iv) soil solution nutrients using suction samplers; (v) organic matter decomposition, in situ and in the laboratory; and (vi) nutrient balances in SP cropping systems. These variables, excluding sweetpotato growth, were also monitored during the fallow periods if applicable.

5.1.1 Specific activities were:

Publication of the Technical report ACIAR technical report no 71, 2009: Soil fertility in sweetpotato-based cropping systems in the highlands of Papua New Guinea.

Exploratory survey to delineate potential soil fertility management options.

The scoping study had identified 'large mound systems' as a best-bet option in semi-permanent SP systems. However this system is only used in the high altitude areas of PNG. A review of the literature on fertility management of soils formed by the influence of volcanic ash clearly showed that organic matter addition using compost of various types and legume rotations are the most suitable soil fertility management options. To further delineate soil fertility management options likely to be adopted by farmers, an exploratory survey was conducted to try to identify small holders who had cropped SP successively without yield reductions or deterioration to the nutritional value of tubers. Nutritional analysis of SP tubers and nutrient analysis of organic amendments, were conducted at UQ.

To identify potential nutrient limitations a nutrient omission trial was conducted. This was a simple pot trial, conducted at Aiyura, on soils collected from each of the three regions where the field experiments were to be carried out.

The results from the exploratory study along with those from the nutrient emission trial were then used to identify the best-bet soil management practises for the process study field trials.

Establish controlled experiments in 3 sites to monitor key soil, water, erosion, nutrient processes in relation to SP growth cycles/seasons in existing SP systems

This activity followed the previous activity. Trial sites were set up: (i) Aiyura site < 1700 m.a.s.l. (ii) Kundiawa 1700-2400 m.a.s.l and (iii) Tambul > 2400 m.a.s.l. Soil management treatments included: (i) Composted mounding; (ii) Short natural fallows or improved fallow (4-12months); and (iii) Legume rotations.

Detailed site assessments with soil profile descriptions were made at all three sites.

Soil water movement monitoring devices (FDR probes) and soil solution samplers were installed in selected treatment plots, including fallow as well as cropped plots.

Due to the intensive monitoring requirements (soil and climate), the full suite of instrumentation equipment could not be used on all treatments. Instead, instrumentation was restricted to treatments where we anticipated the best results in terms of tuber production.

Quantify soil water and nutrient dynamics

While the process trials were running, soil water contents were monitored and soil solution samples regularly collected for nutrient analysis. Plant samples were collected in each season for plant tissue analysis. SP varieties common in the region were used in each trial. All data were compiled in a database. Data recording and analysis by NARI staff were considered an important component of the capacity building objective (3)

Synthesise results with respect to developing on-farm activities in Objective 2 and 3 (in collaboration with CP/2004/071, mid project review)

During the process study the mid-project review was held, at which the results from the process study were summarized and linked to the SP variety project (CP/2004/071), thus setting the scene for the ‘on-farm’, farmer-managed research phase of the project.

Develop soil nutrition information packages and soil and tissue testing protocols for sweetpotato production systems in Australia (targeted component underpinning Australian component of CP/2004/071)

Upon completion of the mid-term review we attempted to compile a preliminary information system for SP nutrition and a fertiliser management package for SP producers in PNG and Australia. However, this was only partly achieved.

5.2 Objective 2. To develop, implement and evaluate improved nutrient and water management options for SP-based cropping systems

The ‘mother’ trials were continued and ‘baby trials’ set up based on observations from the mother trials. The baby trials were part of the famer field-school (FFS) activities.

Specific activities were:

Develop improved nutrient and water management options with farmers and NGOs

The mid project review identified small composted mounds as the best-bet farmer adoptable option for soil fertility management in SP systems. This was promoted as part of the farmer field schools.

Implement mother and baby trials to evaluate management options

The original plan was to move and install our monitoring equipment into selected farmer’s fields to assess changes soil water and nutrient balances under ‘real’ conditions to assess the validity of the results in the process study in objective 1. This was impossible to implement and only yield data and observations on pest and disease were obtained.

Evaluate/fine tune continuous improvement cycle

Fine tuning of fertility management was an iterative action learning type activity during the famer field schools. A total of over 5000 farmers attended the FFS.

Develop adoption pathways through knowledge sharing with other agencies to ensure wider dissemination of research outputs

Throughout the phase of Objective 2, farmer's field schools were conducted by our lead trainer (Jo Kuru and CDA Kundiawa). The field trials associated with the farmer field schools were entirely driven by farmers. NARI and UQ's engaged in data collection, i.e., mainly SP yields, although even this information was very limited.

5.3 Objective 3: To enhance soil research capacity in PNG

Activities under Objectives 1 and 2 were an integral component of Objective 3. Training in soil science was achieved through problem based learning at all levels of collaboration, i.e. learning by doing and working together. Special training programs in the use of soil and plant analysis, and in how to carry out these analyses, were provided to technical staff from Aiyura through on-site hands-on training in PNG and also at the UQ research facilities (lab and glasshouse).

Specific activities were:

Support relevant training of NARI laboratory personnel at Kila Kila and Aiyura

The project allowed for three NARI soil scientists to participate in a 2 months training program at UQ. This training program exposed NARI staff to the Analytical Service Section at UQ in the School of Land, Crop and Food Sciences. They were also attached to field work relevant to the project such as water balance studies on lysimeters conducted by Drs Bah and Kirchhof, as well as soil water and solute movement modelling and advanced data analysis with Dr Kravchuk, a statistician at UQ. Two candidates, Issac Taraken and William Sirabis, visited UQ for the training program, but unfortunately no suitable novice with sufficient background in soil analysis from the Kila Kila lab could be identified. It was therefore impossible for UQ lab staff to deliver the required training in laboratory techniques. The candidates for the training program were scheduled to have the opportunity to participate in the Australian component of ACIAR's SP project CP/2004/071 with DPI&F in Rockhampton and Kairi in North Queensland; but this did not happen.

Develop basic lab facilities in Aiyura and train local technicians

The project provided much needed infrastructure for laboratory and field facilities at Aiyura, including field equipment to assess soil physical and soil structural parameters, instruments to assess soil solution nutrient concentration as well as equipment to monitor soil water balances and climate. This infrastructural improvement at Aiyura was closely linked with training on the use of the new equipment as part of the project's Objectives 1 and 2. The emphasis was on training to deliver independent research capability including competence in statistical analysis.

Specifically, the project provided two types of high-tech equipment: Frequency domain probes (FDR) to monitor soil water contents, and weather stations. The latter was of universal use for all field trials but unfortunately all of the said equipment subsequently failed due to inadequate maintenance.

The project also provided low-cost equipment for in-situ soil solution concentration assessment, tensiometers and suction samplers as well as soil sampling equipment. While the latter equipment was low-tech, it was robust and required minimum maintenance, thereby enabling NARI to conduct basic soil research beyond the life of the project.

We used semi-quantitative low-cost methods to analyse nutrients in soil solution, i.e., simple test strips (Merckoquant) and a photometer (Lovibond) were purchased. Whilst the nutrient test strips worked well for nitrate, the photometer was never installed as NARI was unable to provide a clean room at the Aiyura Station were the instrument could be used.

Targeted training in new soil science methodology relevant to project

This was part of the previous activity and was expected to expand beyond NARI staff to personnel outside the formal collaborators such as Schools and Universities.

6 Achievements against activities and outputs/milestones

Objective 1: To assess and quantify soil and water processes affecting SP growth in PNG Highland soils

no.	activity	outputs/ milestones	completion date	comments
1.1	Review past published/documented soil/agronomy research relevant to PNG highland soils (link to publication of scoping study results)	ACIAR technical report published	31-May-08 completed	Published TR71: Soil fertility in sweetpotato-based cropping systems in the highlands of Papua New Guinea
1.2	Exploratory survey to delineate potential soil fertility management options	Workshop completed Training completed Exploratory work completed	29-Feb-08 completed	The project initiation workshop was conducted at Aiyura in May 2007. Training in the use of the project's methodology and instrument use was conducted during visits by Gunnar in April/May and Oct 2007 and March 2008. Although this activity is completed in 2007, it required further attention whilst trials were being run to ensure ongoing project success. The exploratory surveys in EHP, Simbu and WHP were conducted by LDS in Oct/Nov 2007 and in Enga by NARI in Dec 2007. Results nutritional value of the SP tuber samples were published in the International Journal of Food Science & Technology, 2010, 45, 1925–1931. The SP soil nutrient rate and nutrient omission trial (pot trials) were conducted in Aiyura from Oct 07 to Mar 08 and are completed
1.3	Establish controlled experiments in 3 sites to monitor key soil, water, erosion, nutrient processes in relation to SP growth cycles/seasons in existing SP systems	Infrastructure supplied and in operation Field equipment was installed and operated throughout the project. A project database was developed Trials undertaken	31-May-08 Completed	All equipment for the project was delivered to NARI on/before Nov 2007. It was installed, tested and training in its use conducted. All equipment was installed and was used in the 'mother trials'. The development of the project database was completed in Mar 2008 and was updated throughout the duration of the trials. The 'mother trials' were designed and installed in Simbu (Kondiu High school), WHP (NARI Tambul station and EHP (NARI Aiyura station) in Mar/Apr 2008.

1.4	Quantify soil water, nutrient dynamics by variety and physiological influences in by monitoring crop physiological changes for the development of critical tissue level criteria in response to soil treatments	Monitoring data available Monitoring data analysed and database on process studies completed Monitoring data and database available to CP2004/071	30-Aug-09 ongoing	Phase 1 of the process study was completed, i.e. cropping phase and fallow phase, and Phase 3 commenced early 2011 and harvesting of SP was completed in mid-2011. NB during the mid-term review we decided to have 3 instead of 2 phases which extended activity 1.4 by one year. The Simbu trial was abandoned after phase 2 due to ongoing problems RE trial maintenance A results database was developed and used to support the consolidation and analysis of the data from this complex trial.
1.5	Synthesise results with respect to developing on-farm activities in objective 2 and 3 (in collaboration with CP/2004/071, mid project review)	Relevant data from the two projects combined and model parameterised Mid project review conducted and recommendati on submitted to ACIAR	01-Jun-09 ongoing	Data about the physiology of root thickening has been supplied to DPI&F.
1.6	Develop soil nutrition information packages and soil and tissue testing protocols for sweetpotato production systems in Australia (targeted component) underpinning Australian component of CP/2004/071)	soil nutrition information packages published	02-Mar-10	The NARI team has developed posters for dissemination to farmers groups in support of our outreach component.

PC = partner country, A = Australia

Objective 2: To develop, implement and evaluate nutrient and water management options for SP based cropping systems

no.	Activity	outputs/ milestones	completion date	comments
2.1	Develop improved nutrient and water management options with farmers and NGOs	Initial trials established and completed	01-Jun-10	A total of 19 Farmer Field Schools has been conducted; about 2200 farmers participated the training.
2.2	Implement mother and baby trials to evaluate management options	Monitoring complete after 2 years of mother and baby trials 4 farmer field schools conducted at each of the 3 sites	01-Jun-11	Farmers field schools commenced mid-2009 and continued for the life of the project, baby trials were undertaken using the farmer as researcher model.

2.3	Evaluate/fine tune continuous improvement cycle	Revised soil fertility management options confirmed and modified 4 farmer field schools conducted at each of the 3 sites	01-Jun-10	Data analysis confirmed findings from initial mother trials.
2.4	Develop adoption pathways through knowledge sharing with other agencies to ensure wider dissemination of research outputs	Review completed and project outcome submitted to ACIAR	31-Aug-11	Commenced as part of the outreach program

PC = partner country, A = Australia

Objective 3: To enhance soil research capacity in PNG

no.	Activity	outputs/ milestones	completion date	comments
3.1	Support relevant training of NARI laboratory personnel at Kila Kila and Aiyura	Training output reports submitted to ACIAR for each visit	31-Aug-09	The second of three training program was completed. Mr William Sirabis spent 6 weeks at UQ from the 10th April to the 24th of May 2011. The final training activity for Kila Kila staff was not achieved as suitable candidates could not be identified
3.2	Develop basic lab facilities in Aiyura and train local technicians	Trial sites were installed and monitored	31-May-11	Training in the use and application of scientific methods and instruments was an ongoing activity for the life of the project.
3.3	Build capacity and technical ability of LDS	Field days were reported in local media	31-May-11 ongoing	LDS was excluded from the project because of staffing difficulties. A lead famer and farm educator was contracted to fulfil this role, and successfully conduced an outreach program.
3.4	Targeted training in new soil science methodology relevant to project	Training output reports submitted to ACIAR for each visit	31-May-11 ongoing	Training in the use and application of scientific methods and instruments (appropriate to the setting) continued throughout the life of the project.

7 Key results and discussion

Broadly speaking, the project had 5 main components: (i) an exploratory survey to identify potential soil management practises for trialling. This was combined with (ii) a pilot assessment to assess variety differences in the nutritional value of sweetpotato and whether or not this is related to soil properties. The next step (iii) was a nutrient omission trial to delineate particular nutrient deficiencies followed by (iv) a process study to evaluate sweetpotato yield in relation to soil management and soil water movement. The final component was (v) baby trials coupled with farmer field schools to promote soil management strategies suitable to reduce nutrient deletions.

7.1 The exploratory survey

The exploratory survey to help design best-bet treatments for the process study was conducted in late 2007. This task was conducted by the Lutheran Development Service (LDS). Due to staff changes within LDS our key collaborator left for study leave to the UK and was replaced by a staff member who failed to deliver the survey successfully because of high levels of conflict with the local community. This led to the exclusion of LDS from the project. Due to the small number of farmers (15) surveyed the results were somewhat limited. The main findings are outlined below:

- Half of the farmers interviewed were female, this was important for our on-farm trials and the inclusion of female farmers as decision makers
- All farmers were willing to work with us but a few didn't want to share results with others. This response highlighted the need for improved communication between agency staff and the rural community.
- Cropping cycles seemed short (1-2 crops over 1-2 years) followed by a short fallow (3 months to 1 year). This seemed to apply to all provinces.
- Short fallows were the same as bush fallows. There were no improved fallows where farmers strategically establish fallow vegetation. These fallows were weedy regrowth, primarily voluntary grasses.
- No mineral fertiliser was used, except one farmer who appeared to be a larger scale operator who also used coffee pulp as an organic fertiliser.
- Green manure and compost were mainly grasses. These grew in gardens and there didn't seem to be much 'slash and carry'.
- Availability of organic material for mulch and/or compost seemed to be a major constraint! This was important for designing the type and quantity of organic trash to use in the process study.

Except for Enga and WHP, where compost mounds are in use, inadequate information was obtained about tillage methods used in EHP and Simbu.

These results mirrored the findings from the scoping (ACIAR Project SMCN/2005/043) and provided no new information.

7.2 Nutritional value of sweetpotato

Sweetpotato samples were collected during the exploratory survey and analysed for total starch content and in-vitro starch and K-digestibility. Varieties were: Bayer, Carot Kaukau, Whagi Besta, Nillgai and 1 Mun which were the most common varieties at that time. It is important to note that new varieties that give good yield propagate through the Highlands rapidly and that these tested varieties were the dominant types grown at the time of collection, they had been replaced by other varieties by the end of the project.

Starch content of tubers ranged from 50 to 67%, and was lowest for varieties Bayer and Carot kaukau, and highest for varieties Nillgai and 1 and 3 Mun. Bayer Kaukau also tended to have the fastest starch digestibility, which may be linked to its low starch content. Nutritionally, this indicates that Bayer Kaukau tubers have a high glycaemic index, and are capable of raising blood glucose levels faster than tubers from other varieties.

The samples differed significantly in their K-digestibility, the fastest K-digestibility being observed for varieties 1 Mun and Whahi Besta, and the slowest for variety 3 Mun. Assuming favourable conditions, high K-digestibility can translate into high K-absorption in the digestive tract leading to high K availability after consumption.

The in-vitro digestion methods used measure the digestibility of fresh tubers. However, it is important to note that food preparation, e.g. cooking or roasting, will also impact on digestibility.

There was no relationship between plant tissue nutrient concentrations and tuber starch content or digestibility. However, tuber starch content was highest on soils with high organic carbon, total N and plant available S concentrations.

7.2.1 Conclusion

Results clearly showed that the nutritional value of sweetpotato tubers differed between varieties with some indication that it is also affected by soil fertility. In practical terms however, these results are of limited value for decision making about variety selection to reduce soil fertility decline or improve human nutrition. A more comprehensive study would be needed to link soil fertility to sweetpotato nutritional quality and how food preparation alters nutritional value.

7.3 The nutrient trials

Fertiliser requirement trials were conducted to assess optimum fertiliser application rates and nutrient limitations. Sweetpotato vines were planted into 1L plastic pots containing soil from each of the three trial sites (where process studies were conducted - see section 7.4.1, page 24) and grown for 5 weeks. The pot trial comprised two stages: a nutrient rate trial and a nutrient omission trial.

7.3.1 Nutrient rate trials

Nutrient rate trials in which the application rate of all basal nutrients were altered together were conducted on soils from all three trial sites. The aim of these trials was to determine an appropriate “all” nutrient treatment for subsequent omission trials, thus optimising the capacity of the omission trials to identify nutrient deficiencies. The pot trials were conducted using sweetpotato cutting from the field experiments. They were run for around 5 weeks. The equivalent nutrient rates for a ‘normal’ rate are given in Table 1:

Table 1. Fertiliser rates for the normal (1x) rate.

Nutrient	rate, kg/ha
P	28
K	80
Ca	34
Mg	28
S	24
Fe	5
B	2
Zn	4
Mn	4
Cu	3
Mo	0.4
N	95
Ni	0.1
Lime	5000

Whilst the rate trial for the Aiyura site clearly showed that a 2 x normal rate resulted in optimum growth (Figure 1), the results for the Simbu and Tambul site were too variable. Due to time limitation we assumed that a 2 x normal rate would be suitable for nutrient omission trials on soils from all three sites.

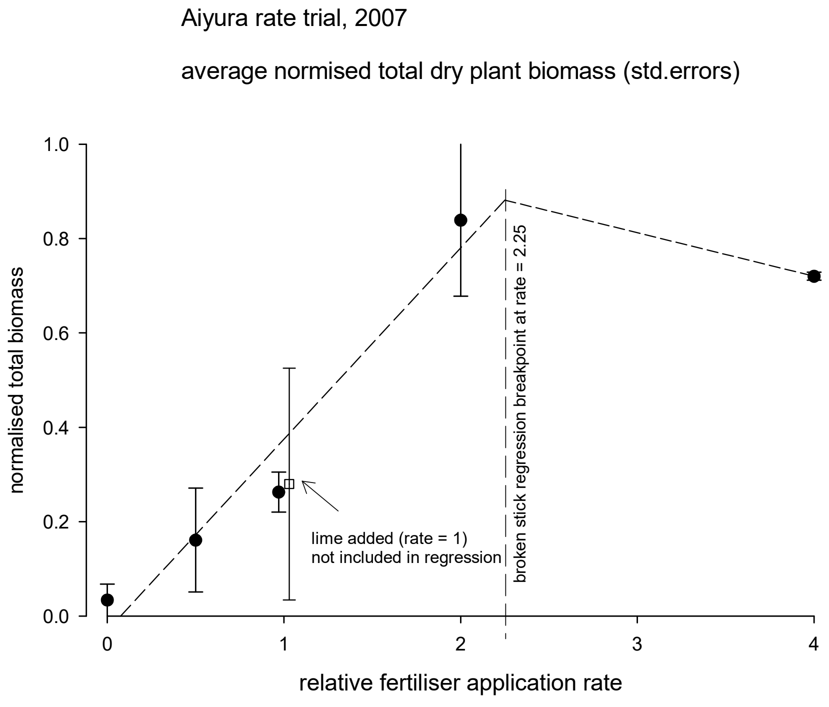

Figure 1. The fertiliser rate trial for the Aiyura soil.

7.3.2 The nutrient omission trial

Following the nutrient rate trial, nutrient omission trials were conducted using the same experimental procedure as the rate trial, but using the 2 x normal rate. The omission trials involved omitting one nutrient at a time from the 'All' nutrients treatment, and in this way identifying which nutrients may be limiting to plant growth on each of the three soils. Nutrient interactions are not investigated in the omission trial approach.

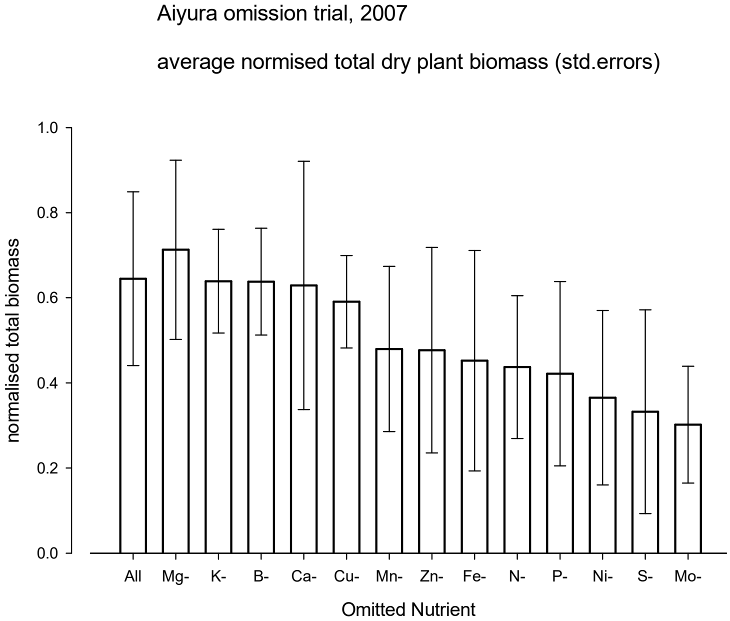

Photo 1. S-deficiency

Figure 2. Nutrient omission trial on the Aiyura soil.

On the Aiyura soil (Figure 2Figure 1), only the biomass yield on the minus Mo treatment was significantly different to that on the 'all' control. However, although the yield on the minus S treatment did not differ significantly from that on the control, very distinct S deficiency symptoms were observed, i.e. the leaves were pale green to yellow in coloration (Photo 1). It should be noted that the high level of variability within the experiment probably prevented the identification of statistically significant effects on biomass yield caused by other nutrient omissions. Hence there is the need to rely to a greater extent on data other than plant dry weight - plant nutrient deficiency symptoms being particularly useful.

Table 2. Plant tissue analysis for the Aiyura soil pot trial, critical levels from O'Sullivan et al 1997.

Treatment	% N	% S	ppm Mo
all	**3.10**	**0.14**	**0.57**
No Mo	3.29	0.17	**0.38**
No N	**2.02**	0.16	0.69
No S	2.93	**0.11**	0.52
Critical level	***4***	***0.34***	***0.2***

The effect of Mo-, N- and S- limitations was confirmed by plant tissue analysis when comparing the relevant nutrient omitted treatments to the 'all' treatment (Table 2). However, these results did not correspond to reported critical levels. Even the 'all' treatment had lower than critical levels for N and S, whereas Mo appeared to be adequate in all treatments (O'Sullivan et al., 1997).

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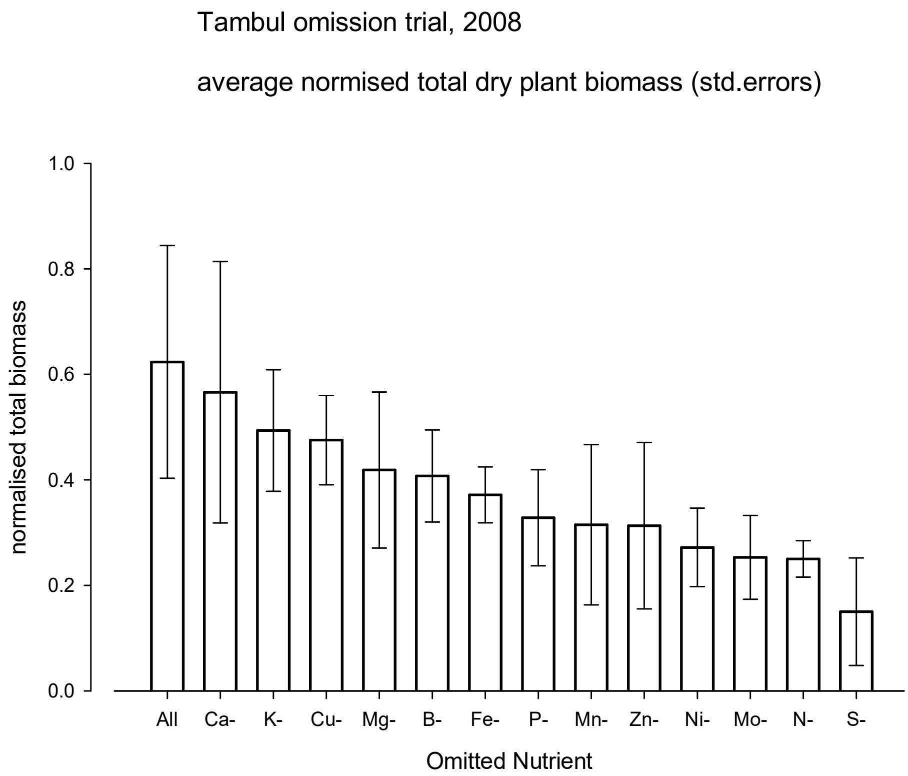


Figure 3. Nutrient omission trial on the Tambul soil.

On the Tambul soil, the following minus nutrient treatments had biomass yields significantly different to that on the 'all' control (Figure 3): minus N, P, S, Mn, Zn, Mo, Ni with minus S having the most significant impact on shoot biomass production. The results of plant tissue analysis confirmed that tissue concentrations of these nutrients were low on the respective minus treatments compared with those for the 'all' treatment (Table 3). However, despite the high fertiliser application rates, even the 'all' treatment had shoot N, S, Mo and P concentrations lower than the reported critical concentrations for SP (O'Sullivan et al., 1997).

Table 3. Plant tissue analysis for the Tambul soil pot trial, critical levels from O'Sullivan et al 1997.

Treatment	% N	%S	ppm Mo	% P	% Mn	ppm Zn
all	**3.47**	**0.25**	**1.65**	**0.14**	**266**	**38**
Mn-	3.49	0.25	1.33	0.13	**160**	48
Mo-	3.41	0.24	**0.26**	0.13	261	40
N-	**2.27**	0.2	1.75	0.12	320	46
P-	2.96	0.24	1.39	**0.11**	269	37
S-	3.78	**0.12**	3.69	0.15	396	52
Zn-	3.13	0.24	1.24	0.12	273	**35**
Critical levels	***4***	***0.34***	***0.2***	***0.22***	***19***	***11***

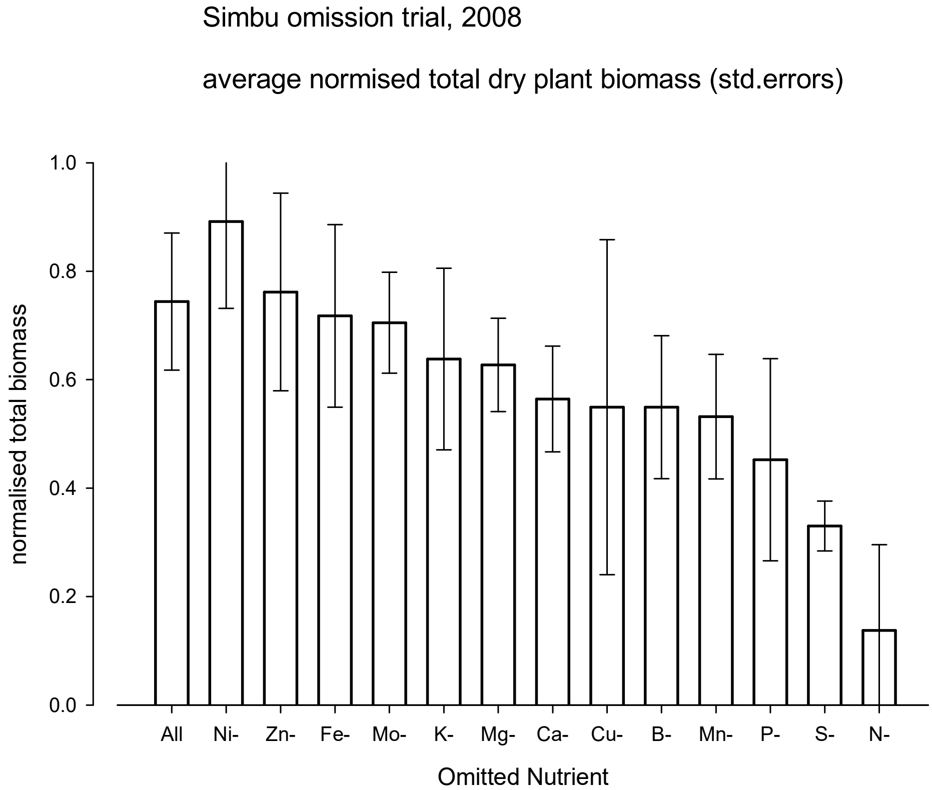


Figure 4. Nutrient omission trial on the Simbu soil.

On the Simbu soil, the following minus nutrient treatments had biomass yields significantly different to that on the control (Figure 4): minus N, P, Ca, S, B and Mn with minus S and N having the most significant impact on shoot production.

Except for P, the plant tissue concentrations for omitted nutrient treatments were lower than those in the 'all' treatment (). However, as in the other two trials, the concentrations of N, P and S in shoots on the 'all' treatment were lower than the reported critical concentrations for SP (O'Sullivan et al., 1997).

Table 4. Plant tissue analysis for the Simbu soil pot trial, critical levels from O'Sullivan et al 1997.

Treatment	% N	% S	% P	ppm Mn	ppm B
all	**2.67**	**0.21**	**0.10**	**90**	**118**
B-	2.93	0.22	0.11	99	**67**
Mn-	2.39	0.20	0.09	**65**	95
N-	**1.49**	0.15	0.12	48	124
P-	2.66	0.20	**0.09**	90	97
S-	2.67	**0.10**	0.10	87	100
Critical levels	***4***	***0.34***	***0.22***	***19***	***40***

These observations cast serious doubts on the application of critical plant tissue levels to identify fertiliser limitations. However, critical concentrations in plant tissue are very dependent on physiological growth stage and decline rapidly as plants mature. It is possible that the plants in the present trials were more mature than those used by O'Sullivan et al. (1997) to determine the critical nutrient levels. Indeed, for this reason, leaf nutrient concentration data from the original scoping study were subjected to a DRIS analysis, which is based on nutrient ratios, as opposed to absolute concentrations, since the former are less affected by crop age (Ramakrishna et al., 2009; Bailey et al., 2009).

A further, even more important limitation of these trials was that nutrient availability under field condition may differ to those observed under pot trial conditions. This is of particular importance for P owing to its interactions with Mycorrhiza under field conditions. The pot trials gave an overall indication of nutrient limitations during vegetative growth, but field trials are needed to assess the effect on tuber yield. The observation that S-limitations were important in soils from two of the three sites supported the results from the Scoping Study. The confirmation that N-limitations were important, despite the high organic matter content of these soils, also supported our hypothesis about an imbalance between the release of N from the soil organic matter and plant demand for this nutrient. Notably, the only nutrient not appearing as limiting in the omission trials was K, even though the results of the Scoping Study showed it to be a major limitation on SP production throughout the Highlands region. However, in the present trials, the soils in question had been fallowed and therefore K reserves may have been adequately replenished. Moreover, the trials did not assess crop nutrient requirements during the tuber phase of growth when K requirements are greatest.

7.3.3 Conclusion

Sweetpotato grown by subsistence farmers is not fertilised. The results from these pot trials are based on very high fertiliser application rates, e.g. 200 kg N/ha. These rates are even in vast excess of what would be used by commercial growers in Australia. Only under these conditions were we able to identify nutrient limitations, which do not represent field conditions. Furthermore, the pot trial was only conducted for 5 weeks and does not give any information about nutrition in relation to sweetpotato tuber yield. Moreover, such high N-rates are likely to encourage top biomass growth and promote the formation of pencil root and reduce tuber yield. Although the pot trials confirmed nutrient limitations observed in the field, e.g. S, they were of limited value for rationalising soil fertility management options which could be used as treatments in the process study. The most important result from these trials was the potential for Mo-deficiency to occur, since this has implications for legume growth, e.g. peanut. There may be merit in pursuing some of the potential micro-nutrient deficiencies identified, including Ni deficiency; however this was clearly outside the scope of the project.

The high variability of the results obtained for sweetpotato in pot culture does call into question the value of this approach. Pot trials do provide additional information on the plant availability of nutrients, however they should be used to guide future field based studies rather than acting as an end point. We suggest that future studies of this type should use an indicator plant for the pot trial phase (e.g. Maize), then move to use of sweet potato at the field testing phase.

7.4 Process study

The aim of the process study was to test different soil management strategies to improve or maintain sweetpotato yield and investigate nutrient balances and potential for nutrient leaching in the high rainfall environment of the Highlands. This was achieved through monitoring sweetpotato growth and yield, and logging of metrological and soil water content and water potential data.

7.4.1 Site and soil characterisation

The initial aim of the site selection was to have 3 sites on different soil types and at different altitudes so that the results would be applicable to a large part of the Highlands. In reality however, the site selection was governed by practicality and security. The 3 sites selected were at the NARI Aiyura station, Kondiu High School (Simbu) and the NARI Tambul station.

The soil profile at each site was described based on at least one soil pit of 1 m in depth, and on physical and chemical analysis conducted on the soil material from the different horizons.

Aiyura

Site description:

- Northerly slope
- ~ 25° inclination
- Mid slope
- Voluntary regrowth, mainly 'may grass' (flowering)
- Land fallow for 5 years +
- WGS84: Lat 6.346158° S, Lng 145.903573° E, Alt 1650 m
- Total dry biomass 15-65 t/ha (May Grass)

Profile description

Soil profile (Humept):

A, 0-20 cm

- Abundant roots, some earthworms visible
- Very moist
- Sub-angular 2-10 mm aggregates
- Silty Clay
- 2.5 YR 2.5/1 (high organic matter of about 10%)
- Very few concretions (up to 5 mm)
- Wavy but clear boundary to

A/B, 20-30 cm

- Many roots
- Moist
- Sub-angular 2-5 mm aggregates
- Clay Loam
- 10 YR 3/2
- Some Fe/Mn-concretions (up to 5 mm)
- Wavy but clear boundary to

B1, 30-50 cm

- Many roots
- Moist
- Sub-angular 2-5 mm aggregates
- Gravely Loam
- 10 YR 3/4
- Many hard Mn-concretions (~30%)
- Wavy and diffuse boundary to

B2, 50-70+ cm

- Few roots
- Moist
- Sub-angular 3-12 mm aggregates
- Loam
- 10 YR 5/8
- Some soft black Mn-concretions

Photo 2. The Aiyura soil profile

Table 5. Soil physical characterization of the Aiyura soil

horizon	Mean BD , g/ml	Mean k_{sat}, mm/h	StDev of ksat, mm/h	%gravel
A	0.78	207.73	264	15*
B1	0.99	23.94	17.8	24
B2	0.94	6.60	6.44	54
B3	0.98	0.62	0.77	53

It is important to note that, despite low bulk densities, hydraulic conductivity was very low below 30 cm. This indicates a potential for nutrient leaching laterally, rather than vertically.

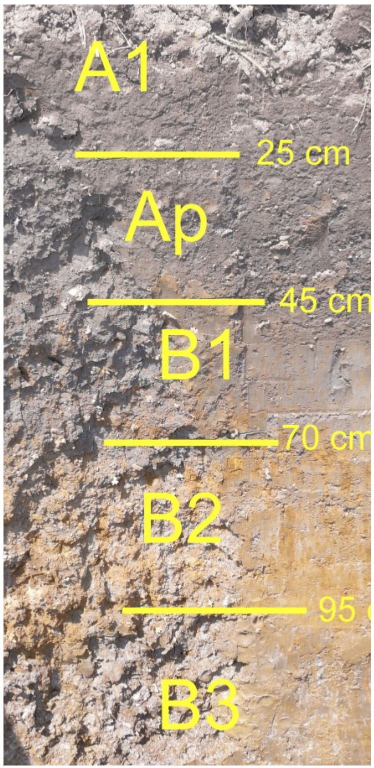
Table 6. Soil chemical properties of the Aiyura soil

horizon	fraction	pH (1:5 water)	%C	%N	C:N ratio	ppm S	CEC cmol(+)/kg
A	gravel	5.88	1.66	0.14	13.02	9.11	5.56
A	soil	5.81	6.49	0.44	14.91	8.14	11.57
AB	gravel	5.75	1.41	0.09	15.56	10.18	5.67
AB	soil	7.00	3.98	0.25	15.94	8.07	10.26
B1	gravel	7.38	1.03	0.07	13.50	3.93	8.07
B1	soil	6.77	1.36	0.10	15.41	5.41	6.46
B2	gravel	6.98	0.43	0.04	10.61	5.45	4.21
B2	soil	6.53	0.74	0.06	13.32	4.44	4.57
B3	gravel	5.84	0.26	0.02	11.81	18.77	3.14
B3	soil	5.74	0.52	0.05	9.92	27.46	6.45

Simbu (Kondiu High School)

Site description:

- Slightly sloping towards river flat
- Mid slope (centre of trial area)
- Voluntary regrowth, mimosa and calepo
- Part of land cleared 4 recently, remainder under fallow for 4 months (35-65 t fresh biomass, ~13-23 t/ha dry biomass)
- WGS84: 5.981868° S, Lng 144.852142° E, Alt 1454 m (GPS)



Soil profile (Aqept):

A1, 0-30 cm

- **Some roots**
- **Moist**
- **Angular blocky 10 aggregates**
- **Silty Light Clay**
- **Brown**
- **Diffuse boundary to**

Ap, 25-45 cm

- Few roots
- Moist
- Angular blocky, tend to platy 10 aggregates
- Light Clay (NB: silty consistence due to high organic matter content)
- Brown, slightly lighter then A1
- Diffuse boundary to

B1, 45-70 cm

- Many roots
- Moist
- Sub-angular 5 mm aggregates
- Light Clay
- Light brown with reddish mottles and some coarse fragments, Fe-nodules.
- Very wavy boundary to

Photo 3. Simbu soil profile.

B2, 70-95 cm

- Many roots
- Wet
- Very gravely, mainly angular fragments, possibly colluvium from landslide NB depth of gravel horizon very variable and at 40 cm depth at upper part of trial area.
- Reddish with some black mottles
- Very wavy boundary to

C, 95-130+ cm

- Few roots, root channels with red coatings
- Saturated (water table at ~ 90 cm)
- Sub-angular 5 mm aggregates
- Grey, whitish when dry

A clay soil with a cloddy surface horizon; it breaks to a reasonable tilth after some wetting and drying. The site has been cultivated using a tractor and there is a distinct plough layer below the cultivated zone. The B horizon is affected by fluctuating water tables and shows gleying above a permanently waterlogged zone which is greyish in colour (B3 or C horizon). There is a distinct gravel layer between the B2 and B3/C horizons. The coarse fragments are angular and some are akin to saprolite indicating that this layer was deposited as colluvium from an ancient landslide. The gravel horizon is visible in some drains and can be as close as 40 cm to the soil surface with the greyish B3/C horizon below. The gravel layer appears to act as a drain for the upper B horizons. The material above the colluvium is probably of alluvial origin form the nearly Whagi river.

Table 7. Soil physical properties of the Simbu soil

horizon	Mean BD, g/ml	Mean k_{sat}, mm/h	StDev k_{sat}, mm/h
A1	1.00	87.23	137.37
Ap	0.99	0.35	0.01
B1	1.18	0.24	0.21
B2	1.46	37.33	1.30

The site was compacted from the use of a tractor at the High school, probably by cultivation under too wet conditions. The compaction layer was clearly visible and had low hydraulic conductivity but did not show high bulk density.

Table 8. Soil chemical properties of the Simbu soil.

horizon	fraction	pH (1:5 water)	% C	% N	C:N ratio	%S	ppm Mn	Ca, cmol+/kg	ppm B
A1	soil	5.99	3.72	0.335	11.1	0.84	68	9.81	0.43
Ap	soil	6.25	2.58	0.250	10.3	5.44	30	9.80	0.28
B1	soil	6.48	1.51	0.128	11.8	2.39	11	7.54	0.22
B2	gravel	6.48	0.44	0.045	9.8	9.28	15	2.39	0.45
B2	soil	6.58	0.59	0.048	12.5	3.50	19	3.54	0.27
B3	soil	5.69	0.64	0.046	13.9	4.09	87	5.48	0.26

Tambul soil

Site description

- flat
- centre area of field
- Voluntary regrowth, not identified species
- Land fallow for 2 years +
- WGS84, lat 5.88693° S, Lng 143.95114° E, Alt 2355 m (GPS)

Soil profile (Aquist)

A, 0-30 cm

- Abundant roots
- Moist
- Sub angular blocky 1-3 mm aggregates
- Silty light Clay (NB: silty consistence due to high organic matter content)
- Black
- Wavy but clear boundary to

B1, 30-60 cm

- Many roots
- Moist
- Sub-angular 1-3 mm aggregates
- Light Clay
- Very dark brown
- Wavy boundary to

B2, 50-90 cm

- Few roots, large decomposed root or vermin channels (~1-2 cm) provide drains with red oxidised coatings)
- Saturated (water table at ~ 60 cm)
- Sub-angular 1-3 mm aggregates

Photo 4. The Tambul Soil profile

- Light Clay but very strong aggregated due to high organic matter content.
- Very deep black, probably an old buried A horizon
- Very wavy but clear boundary to

C, 90+ cm, but in the absence of a B2 C also present at 40 cm depth

- Few roots
- Wet
- Sub-angular 1-3 mm aggregates
- Medium Clay with some sandy particles
- Light grey with some orange and few black mottles.

The site is an old lake bed. There were volcanic ash deposits dating back around 70,000 years. Whether the ash was deposited into the lake or after the lake had been already been filled and dried to a swamp is not clear. However, the horizon differentiation suggests that the current B_2 is probably a buried A horizon before the deposition of ash. Bulk densities are very low throughout the profile. Whilst these low values in the A and B horizons are probably due to the peaty or andic nature of the soil, the low values of the C horizon which has relatively low organic carbon contents, suggests ash influence (allophanes) in the subsoil of a buried profile.

Table 9. Soil physical properties of the Tambul soil

horizon	Mean BD, g/ml	Mean k_{sat}, mm/h	StDev of k_{sat}, mm/h
A	0.25	9.49	11.87
B1	0.22	150.10	211.12
B2	0.23	42.09	22.92
C	0.23	5.54	0.45

Table 10. Soil Chemical properties of the Tambul soil.

horizon	A	B1	B2	C
pH (1:5 water)	5.51	6.24	5.85	4.62
% C	21.07	12.01	14.22	6.04
% N	1.30	0.71	0.72	0.27
C:N ratio	16.17	16.91	19.72	22.53
% S	123.40	79.40	9.90	5.10
ppm P(Colwell)	84.30	16.30	8.00	5.00
CEC, cmol+/kg	1.51	0.51	0.40	0.22
ppm B	0.12	0.04	0.06	0.05
ppm Mn	4.30	1.50	1.00	0.40
ppm Zn	1.70	0.50	0.20	0.00

Summary assessment of mother trial soil properties

Table 11. Properties of the soils used in the mother trials.

Property	Aiyura	Simbu	Tambul
pH	Moderately acid	slightly acid	Moderately acid but very acid in subsoil
Organic C	High in topsoil	Moderately high	Very high throughout
Total N	Moderately high in topsoil	Moderately high throughout	Very high throughout
C:N ratio	Intermediate, but low in subsoil	low	Intermediate, but high in subsoil
S	Low, but high in subsoil	low	high, but low in subsoil
P	Moderate, but low in subsoil	Moderate, but low in subsoil	high, but moderate in subsoil
K cmol+/kg	Mixed, but low	Very low throughout	Low and very low in subsoil
CEC	Mixed, moderate	High in topsoil, moderate in subsoil	Very low
B	Low to very low	moderate	Low to very low
Bulk density	Low and uniform throughout	Low and increasing with depth	Extremely low
K_{sat}	Very high in topsoil, low in subsoil	Moderate but very low in Ap	Low in A (cattle), moderate and low

Table 11 gives an assessment of possible limitations to crop production. Sulphur and P are potentially limiting for the Simbu and Aiyura soils, but not the Tambul soil. Potassium is possibly low on all soils. Despite its high levels of organic carbon, the Tambul soil has very low CEC indicating a very poor soil, possibly because of the formation of humus-allophane complexes which had facilitated organic matter accumulation whilst dramatically reducing the free negative charges on the organic material (Bailey et al., 2008). The Aiyura soil has very dense subsoil with low hydraulic conductivity despite relatively low bulk density. This indicates that there may be preferential lateral rather than horizontal movement of water leading to leaching along the slope but with limited leaching into the subsoil. The Simbu soil had a very pronounced compacted layer owing to tractor use.

Soil management treatments used and trial monitoring methods

Soil management treatments were designed to allow the assessment of different cropping system x soil management factors using an unbalanced factorial design where treatment with identical factors could be combined and compared with other treatments of equal factors.

The factors we could assess were:

- Biomass type during the fallow: *none, weeds, Tithonia, Lupins and Peanut*
- Biomass management method: *none, slash and compost, slash and burn*
- Tillage: *large mounds, small mounds, beds*
- Crop rotation: *sweetpotato only, sweetpotato and short fallow, sweetpotato followed by peanut and short fallow*

Treatments are given below in Table 12.

Table 12. Mother trial treatments

Treatment type	Description	Sites	Treatment
Engan_mounds	on-site plant material, 20t/ha	all	1
Engan_mounds	on-site plant material, 50t/ha	Tambul	2
Engan_mounds	on-site plant material and cut	Tambul	3
Engan_mounds	on-site plant material and cut	Tambul	4
Engan_mounds	no composted mounds	Tambul	5
Engan_mounds	burnt mounds	Tambul	6
Small mounds, slash and burn	slash and burn, weedy regrowth	Aiyura/Simbu	7
Small mounds, compost	slash and extra compost	Aiyura/Simbu	8
Small mounds, mulch	slash only, weedy regrowth	Aiyura/Simbu	9
Small mounds, peanut phase	peanut phase	Aiyura/Simbu	10
Small mounds, back2back SP	no peanut phase	Aiyura/Simbu	11
Beds	SP-legume-weedy fallow (3-4 months)	all	12

In year one of the trial, tuber yields were measured at the end of the season. This was changed to sequential harvesting (twice per season) in subsequent years. The change in harvesting methods was implemented to mimic more closely farmer practice and because it was observed that sweetpotato in the Engan mounds needed more time to form harvestable tubers. Total tuber yield was separated by tuber size ranging from large marketable tubers to pencil tubers and rejects used as pig feed. In year one, the root system was excavated and cleaned to assess nodes in relation to tuber size. However, this was too labour intensive and gave no usable results and hence was not continued beyond year one.

Total above ground biomass was recorded at the end of the sweetpotato season and on the fallow biomass before the next sweetpotato season. In year two, the botanical composition of the fallow was also determined.

Soil samples for chemical analysis and plant tissue samples were collected at different time during the duration of the mother trials.

Data loggers were used to monitor meteorological data (rainfall totals and intensities, air temperature, humidity, radiation and soil temperature at two depths). Each logger was also equipped with one FDR probe to monitor soil profile water content. This probe was rotated between different treatments to capture wetting and drying cycles. Tensiometers were used to manually monitor soil water potential and estimate hydraulic gradients. Soil solution was collected in suction samplers and nitrate-concentrations were monitored using test strips.

7.4.2 Sweetpotato yield response

Assessment of SP yields is amongst the most difficult parameters to quantify. Tubers are generally separated into different sizes ranging from rejects to large tubers. Analysis is possible on different tuber sizes or cumulative tuber sizes, and each dataset will give different results. We used ‘useable’ tubers in our analysis by combining yields of small, medium and large tubers and ignoring rejects and pencil tubers. In PNG, tubers are harvested sequentially which adds another factor to the yield assessment, and hence we used the total cumulative seasonal yield in our analysis. Sweetpotato is also a very variable crop with large within plot variation. Our plot sizes were probably too small to separate guard from data plants and therefore we used total plot yield as our indicator of yield.

Crop 1 - 2008

Field sites in Eastern Highlands (Aiyura station), Simbu (Kondiu High School) and Western Highlands (Tambul station) provinces were prepared for sweetpotato planting in April 2008. All sites were brought into cropping from a non-sweetpotato or fallow phase. Sweet potato was grown for 6 months at Aiyura and Simbu, and for 9 months at Tambul; the longer growing period at the latter station was needed because of the colder temperatures at high altitude.

In 2008, tuber yields at Aiyura ranged from 10 to 27 t/ha. The lowest yield occurred on the large composted mound treatment, and was significantly different to the yields on several other treatments. This treatment produced the lowest mass of medium size tubers but also the largest number of small or rejected tubers. It is possible that, if harvested later, small tubers would have grown and reduced the yield difference with the other treatments. Yields on the other treatments ranged from 16 to 27 t/ha but were not significantly different. The general lack of treatment effect was probably due to the long fallow period prior to the study and thus the absence of any soil fertility limitation.

Yields at the Simbu site were similar to those at Aiyura and ranged from 11 to 22 t/ha. However, unlike at the Aiyura site, the large composted mound treatment produced the highest yield. Furthermore, the small mound with compost treatments produced higher yields than those with mulch. This indicated that composting at the poorer Simbu site was beneficial for tuber production.

The high altitude Tambul site had very low yields: 0.1 to 3 t/ha. These low yields were no doubt largely due to the low inherent fertility of the soil. The trial site was situated on an old swamp which had been cleared and drained for grazing a few decades ago. Under these conditions the soil fertility (e.g. CEC topsoil ~1.5 and subsoil <0.5 cmol+/kg) is extremely low despite the very high organic carbon contents (21% topsoils and 10 % subsoil). The site had never been cultivated prior to the trials. Under continuous cultivation the CEC of the soil will improve as organic matter breaks down and soil fertility increases leading to the relatively high SP yields observed in Enga from the large composted mound systems. However, farmers explained that it takes at least 3 years of cultivation before these soils begin to give satisfactory yields. Trials at the high altitude site in Tambul were discontinued following concerns amongst the research team that the site was not representative of typical farmers’ fields in the area.

Crop 2 - 2010

The second sweetpotato cropping cycle was completed early 2010. The Engan mound treatment at Aiyura had the highest yields with 31 t/ha, substantially higher than the first cycle. This may have been because the sequential harvesting used in this cycle had overcome the problem of harvesting immature tubers. At Simbu, the yield for the Engan mound treatment increased to 31 t/ha and was the highest in this cycle. The small composted mounds maintained a moderate yield of 23 t/ha in Aiyura but there was no advantage from using compost in small mounds at Simbu.

Field trials at the Simbu site had to be discontinued late 2011 due to ongoing problems with the upkeep of the trials and concerns about data reliability.

Crop 3, 2012

A third SP cropping cycle was planted at the Aiyura site early 2011. Yields were around 20 t/ha for all treatments except the Engan mounds which yielded significantly higher at 31 t/ha.

Crop 4, 2013

The review team had recommended continuing the last mother trial for a 4th season. This was done but unfortunately the data were not usable as a different method of data recording had been used and the required metadata were not available to calculate yields.

Cumulative yields

From a food security and soil fertility decline perspective, a cumulative yield over the 3 years is more informative than individual season yields. This assessment was only possible at Aiyura. Figure 5 toFigure 8 show the cumulative yields for the different treatments investigated. A yield decline over time would be reflected in a reduction in slope; this was not observed although some yield reduction may have occurred in the back-to-back sweetpotato treatments (Figure 8). Mounds with compost tended to have the highest yields (>60 t/ha) and mulched treatments and beds the lowest yields (<50 t/ha). However, back-to-back sweetpotato had the highest yields (p=0.05). Seasonal yields may be lower, but this was compensated for by yield generation between seasons when the other treatments were under fallow.

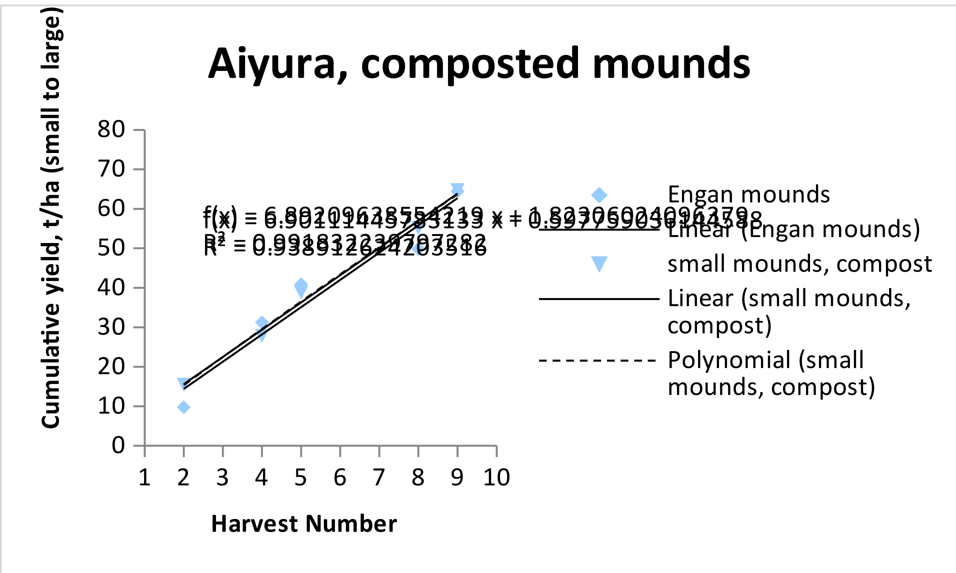


Figure 5. Cumulative yields on mounds with compost.

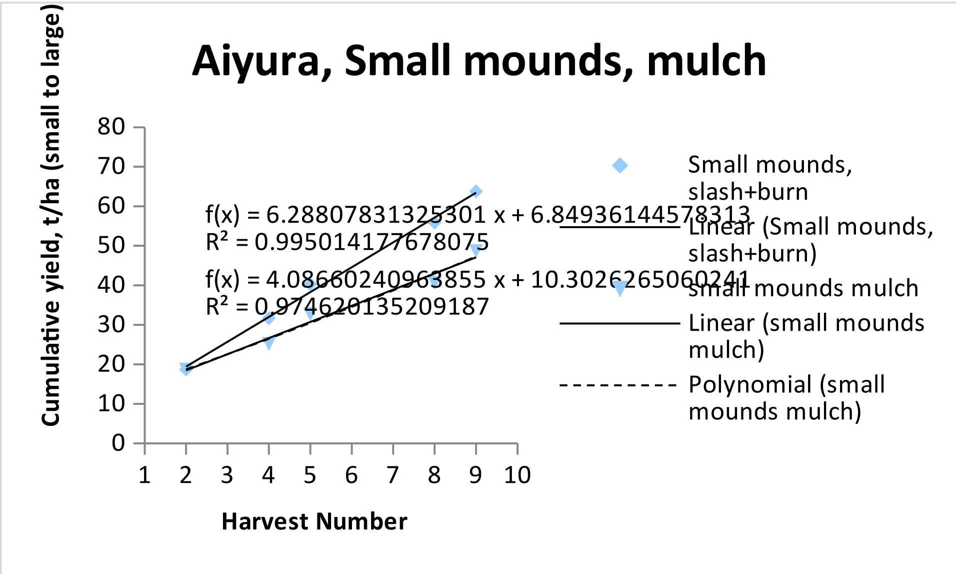


Figure 6. Cumulative yields on mounds without compost

Our data did not demonstrate that soil fertility rundown is occurring, and thus did not support farmer observations from the scoping study. In hindsight, it is possible to argue that the sites we selected were not appropriate: the sites at Simbu and Aiyura had been under fallow for several years allowing them to build levels of plant nutrients far higher than would be achieved in a farmers field after I year. Thus 3 years of cropping may not have been sufficient to precipitate soil fertility decline as is reported by the farmers and indicated in the scoping study. Conversely, these sites were selected because of the past fallow to ensure a starting point of reasonable soil fertility, and from an experimental perspective, a reasonable plot size and uniformity. The data may reasonably be used to support the view that cropping period can be extended without yield loss if a longer fallow is used. An additional important practical argument for site selection was security, which was why the NARI stations in Aiyura and Tambul and the Kondiu High School were selected, even though this proved to be incorrect during the duration of the trial, e.g. the logger was stolen in Tambul and all sites suffered some level of loss of yield through theft!

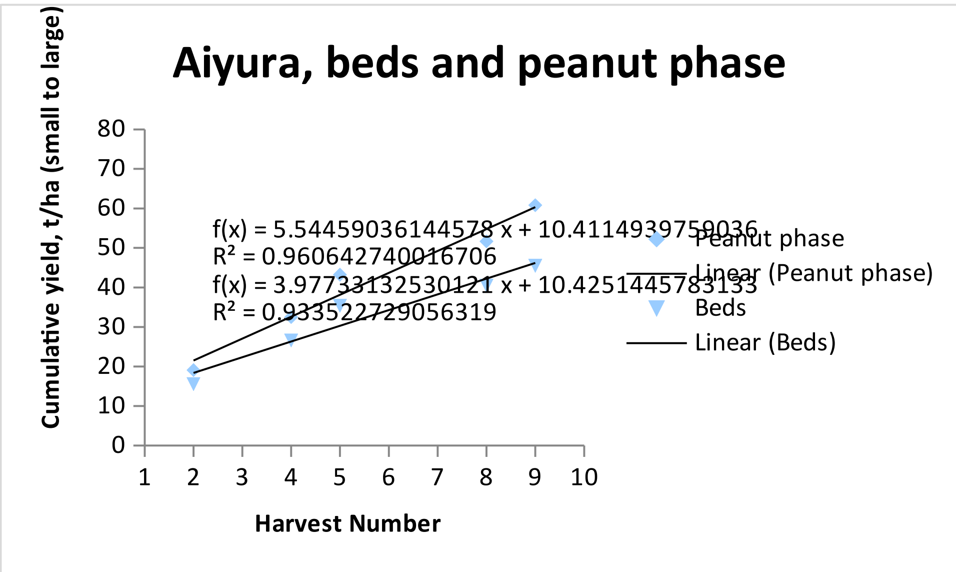


Figure 7. Cumulative yields on beds and with peanut phase.

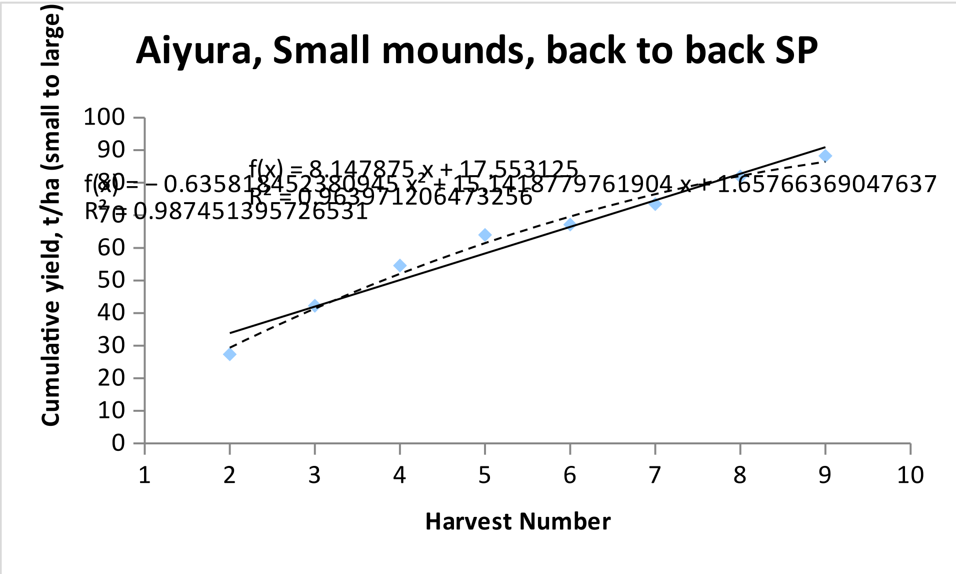


Figure 8. Cumulative yield of back-to-back sweetpotato.

Considering that individual yields of back-to-back SP were lower than the other treatments, and that the treatments with a fallow had the best yields – soil fertility would indeed appear to have been a limiting factor. The negative effect of mulching could have been due to a build-up of pests and diseases under too wet conditions, and the poor performance of a peanut fallow due to the low peanut yields on the Aiyura site (~ 1 t/ha), in part because of theft of the crop despite the presence of security guards. The potential of micro-nutrient deficiency limiting peanut yield should also be considered.

Sweetpotato production on beds is the common method for commercial producers, i.e. the reason why this treatment was included. Our work suggested that this is not suitable, at least not on the Aiyura site. Reasons for this may be the dense and impermeable subsoil ().

7.4.3 Biomass balances and nutrient composition

Soil chemical analyses were carried out at different times during the mother trial. Table 1 summarises the statistical analysis on these tests at the Aiyura site. Although some significant differences were observed, they were in no way related to sweetpotato production and not further analyses were carried out post the 2nd harvest.

Table 13. Soil chemical analysis during the trial

		P-values for treatment effects			
type	soil depth	crop1, 1st	fallow 1	harvest 2	fallow2
pH, water	*top*	0.03	0.47	0.01	0.1
	sub	0.72	0.96	0.01	0.31
%C	*top*	0.59	0.64	0.01	0.01
	sub	0.7	0.14	0.02	0.57
%N	*top*	0.75	0.72	0.09	0.42
	sub	0.67	0.27	0.01	0.82
C:N ratio	*top*	0.42	0.84	0.52	0.49
	sub	0.46	0.57	0.06	0.68
S, ppm	*top*	0.76	0.65	0.65	0.02
	sub	0.91	0.07	0.12	0.72
P, ppm	*top*	0.86	0.72	0.23	0.05
	sub	0.32	0.48	0.11	0.39
Ca, cmol(+)/kg	*top*	0.93	0.34	0.64	0.06
	sub	0.54	0.45	0.01	0.42
K, cmol(+)/kg	*top*	0.14	0.66	0.19	0.17
	sub	0.36	0.8	0.03	0.53
B, ppm	*top*	n/a	0.52	0.34	0.25
	sub	n/a	0.87	0.59	0.64

The same was observed for plant tissue analysis; i.e. some significant treatment differences, but not related to sweetpotato productivity.

As a first step to gauge nutrient balances we calculated nutrient removal from tuber harvest. shows average nutrient contents of tubers and a simple calculation of nutrient removal from a 10 t tuber crop is given in Table 15.

Table 14. Tuber nutrient content

nutrient	average	Std.dev
N, %	0.6	0.3
Ca, %	0.09	0.04
K, %	1.4	0.3
P, %	0.10	0.04
S, %	0.06	0.01
B, ppm	6.7	3.7
Zn, ppm	6.9	2.1

Table 15. Nutrient removal by tuber harvest and nutrient accumulation during the fallow.

10 t dry biomass in mounds	kg N per ha from biomass	kg N per 10 t tuber	kg K per ha	kg K per 10 t tuber	kg S per ha	kg S per 10 t tuber
Aiyura	67	*-18*	57	*-45*	5	-2
Simbu	154		251		13	

Nitrogen should easily be replenished during the fallow phase unless farmers burn the biomass and yields are considerably higher than those commonly observed in farmers' fields. The biomass at Aiyura was mainly may grass with an N-content of 0.7%, at Simbu it was mainly mimosa (1.5% N). Mimosa is not a convenient legume in a fallow due to its thorns, but quite low biomass accumulation would be able offset removal.

Removal of K and S was of more concern. Even a low tuber yield of 10 t/ha could potentially deplete more than can mobilised by a fallow. K or S accumulators will be important to sustain tuber sweetpotato production. There were large differences in biomass K-content: May grass 0.6% and Mimosa 2.5%. Both were low in S (0.05% and 0.13%) and alternative plant species will be needed to maintain S-level, e.g. Tithonia with 0.3% leaf-N (Table 16).

Table 16. Nutrient composition of different fallow species

Nutrient	coffea leaf	Cowgrass compost	Desmodium compost	Fimbristyl compost	Ischaemum compost	Kunah compost	Leucaena leaf	Lupine compost	may grass mix	mimosa, calepo mix	piper leaf	Pitpit compost	Tithonia compost	Tithonia Leaf	Tritium compost
C, %		42.2	45.3	42.9	44.2	43.6		44.5	46.8	48.3		47.9	46.1		45.0
St.dev		*0.2*	*0.4*	*0.7*	*0.7*	*1.5*		*2.9*	*3.2*	*0.1*		*1.7*	*2.8*		*0.1*
N, %		0.42	1.92	0.85	0.49	0.54		2.20	0.67	1.54		1.41	2.98		0.64
St.dev		*0.05*	*0.38*	*0.19*	*0.11*	*0.02*		*0.58*	*0.18*	*0.54*		*1.12*	*0.39*		*0.16*
B, ppm	39.06	7.73	10.94	6.38	8.69	1.40	27.36	18.01	39.71	21.35	45.13	10.38	33.16	47.64	5.29
St.dev		*1.25*	*1.50*	*1.37*	*1.25*	*1.07*		*5.15*	*29.11*	*3.75*		*9.56*	*12.29*		*0.73*
Ca, %	0.36	0.39	0.76	0.36	0.21	0.31	0.90	1.93	0.31	1.38	1.15	0.30	0.89	2.09	0.05
St.dev		*0.09*	*0.13*	*0.12*	*0.01*	*0.09*		*1.11*	*0.10*	*0.21*		*0.12*	*0.17*		*0.01*
K, %	2.75	0.89	1.38	0.65	0.90	0.41	0.70	1.73	0.57	2.51	2.45	0.33	2.73	1.93	1.17
St.dev		*0.36*	*0.46*	*0.06*	*0.22*	*0.17*		*0.60*	*0.23*	*0.88*		*0.18*	*1.07*		*0.19*
P, %	0.16	0.07	0.21	0.11	0.04	0.05	0.22	0.27	0.05	0.15	0.18	0.07	0.30	0.35	0.08
St.dev		*0.01*	*0.07*	*0.00*	*0.01*	*0.01*		*0.09*	*0.01*	*0.04*		*0.06*	*0.06*		*0.03*
S, %	0.15	0.06	0.09	0.05	0.07	0.01	0.31	0.16	0.05	0.13	0.10	0.05	0.18	0.32	0.09
St.dev		*0.01*	*0.02*	*0.01*	*0.02*	*0.00*		*0.03*	*0.01*	*0.03*		*0.03*	*0.04*		*0.01*
Zn, ppm	5.76						41.78	31.88	26.41	21.27	18.60	28.44	32.11	66.02	
St.dev								*1.30*	*13.91*	*2.11*		*7.51*	*5.03*		
									AIYUR	SIMB					

7.4.4 Climate and partial water balances

Three data loggers were used to obtain a comprehensive weather record. Due to security problems, we did not use solar panels to charge the power supply, but replaced and recharged batteries on a regular basis. This proved to be a major problem and the (planned seamless) data we collected had a tremendous amount of gaps to the extent that most of the data were not usable. Additional problems encountered were stolen batteries, damaged soil temperature sensors, blocked rain gauges and complete theft of a whole logger. Figure 9 gives the monthly rainfall data we collected; NB the gaps are not due to drought, but due to flat batteries.

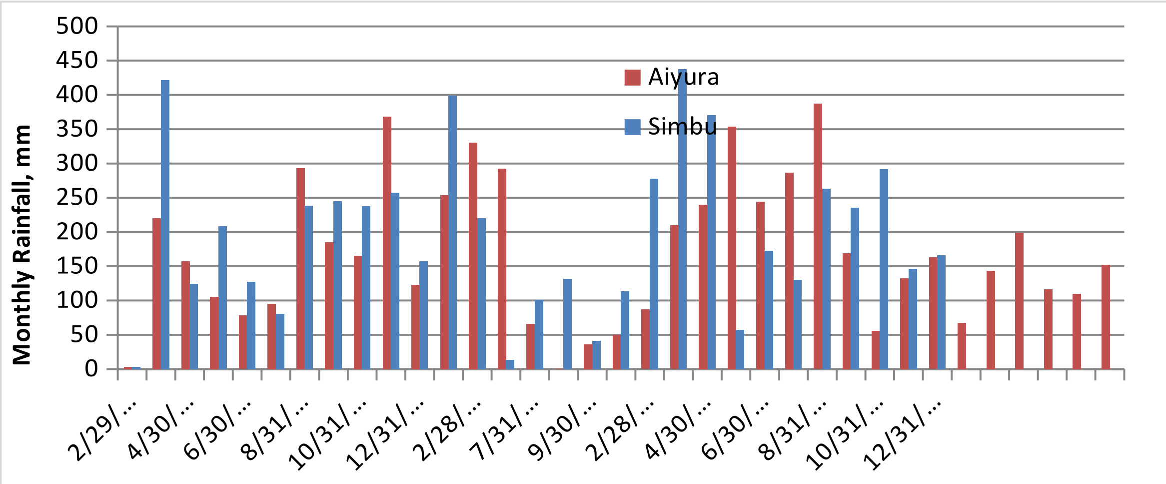


Figure 9. Monthly rainfall record at Aiyura and Simbu.

Manual data collection from tensiometers and suction samplers was more reliable than the high-tech loggers we used. However, as no reliable soil water contents could be measured, we were only able to assess hydraulic gradient as indicators for leaching potential, and suction samplers to show if the soil solution contained nitrate that could be leached.

Hydraulic gradients

Hydraulic gradients were calculated from the tensiometers installed at 20, 40, 60 and 100 cm depth; positive gradients show downwards water movement, negative gradients upwards movement, a gradient of 1 means steady state infiltration. Average gradients were used to investigate the direction of water movement, i.e. leaching potential at the different sites and treatments. Soil management affected water movement at all sites.

Building of Engan mounds requires excavating soil (a crater), filling it with biomass and heaving the soils to create a large mound. It is possible that the biomass is located just above the low permeability subsoil () and creates some water logging and a strong suction downward due to dry soil. This results in a large positive gradient and could cause some leaching (Figure 10), but a negative gradient below (wet subsoil) would compensate for that loss. As saturated hydraulic conductivities were very low, it is unlikely that much leaching occurred despite reasonably strong gradients. In general, the soil surface had negative gradients, i.e. it dried out, except for the bed-treatment which had very small positive gradients, indicating little water movement and possible water logging which may have contributed to the low yields. This was not the case for the mulch-treatment, which suggests that other factors such as pathogens may have impacted on yield. The significantly higher negative gradient in the peanut-treatment remained unclear.

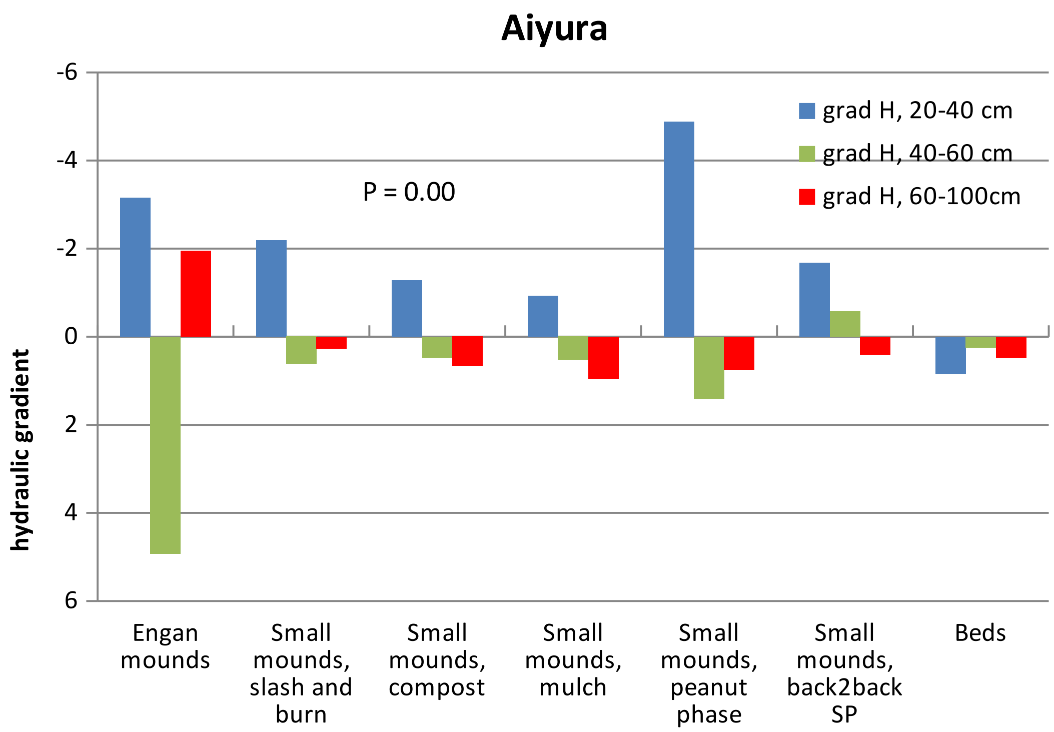


Figure 10. Hydraulic gradients at Aiyura

Hydraulic gradients at Simbu were always very close to zero, possibly because of the compacted layer at plough depth. At this site the mulch treatment had an average gradient of just below one, showing that more water was infiltrating under mulch and keeping the soil wetter and reducing water loss. The warmer climate at Kondiu is probably related to this observation.

Gradients at Tambul were all positive. This shows a leaching environment which is not surprising in this swampy environment with high water tables. Due to the low fertility of the soil, there was probably not much nutrient that could leach to the water table, but if the small amounts of nutrients that are in solution leach, it amplifies the low fertility of the soil. Once the organic matter starts mineralising and soil fertility improves, leaching could lead to nutrients losses, but they may not be apparent while sufficient organic matter is present.

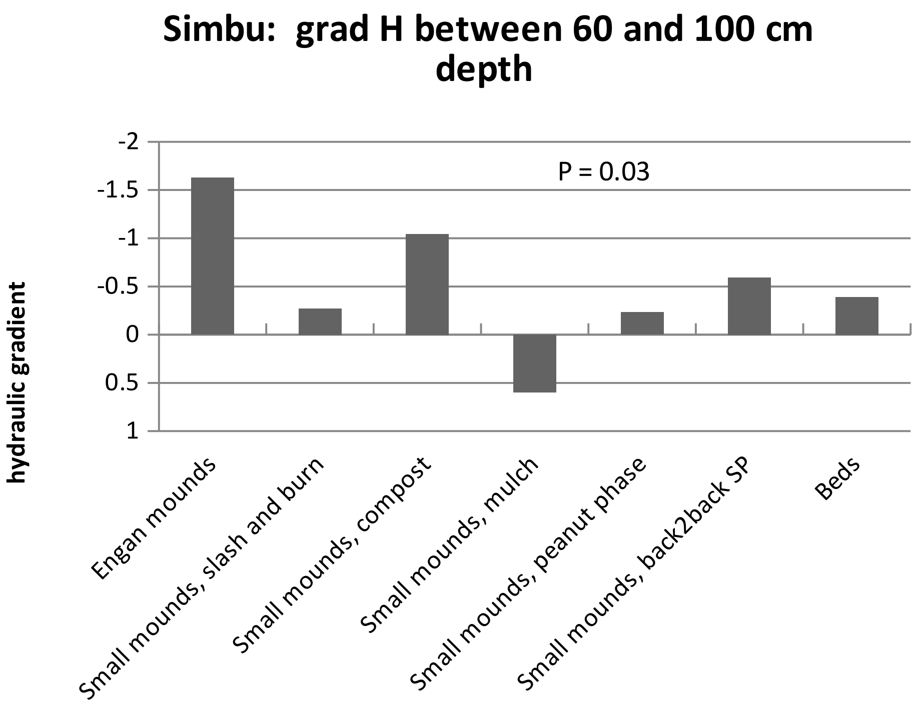


Figure 11. Hydraulic gradient at Simbu (no significant differences 20-40 and 40 - 60 cm depth).

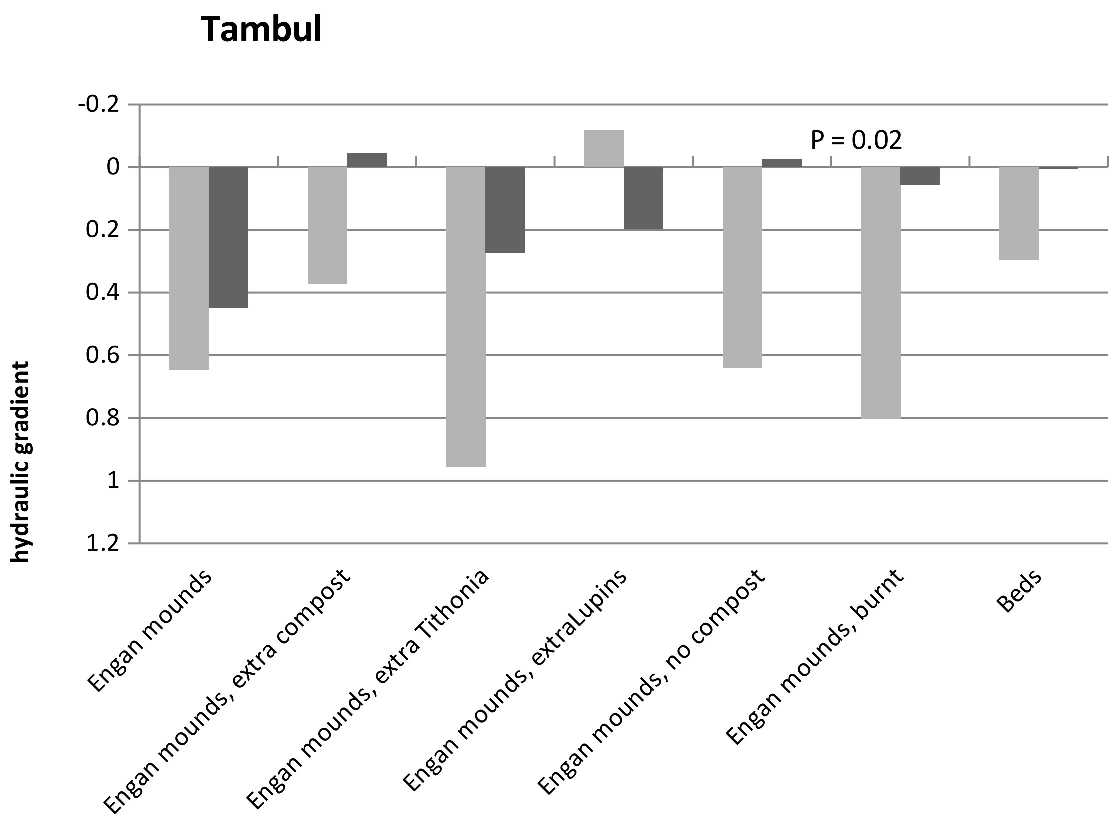


Figure 12. Hydraulic gradients at Tambul (no significant differences at 40-60 cm)

Soil solution nitrate

Our observations on direction of water movement were similar to the last cycle, i.e. a leaching environment in Simbu with little nitrate detected in the soil solution from the rooting depths, and an upward redistribution environment at Aiyura with nitrate present in the rooting zone.

Topsoil solution nitrate levels were always higher at the Aiyura site (17 mg/l) compared to the Simbu site (2 mg/l), which would account for the yield difference. It also corresponds to differences in topsoil organic carbon contents (3 and 6%). Leaching of nitrate from the topsoil is possible in Simbu where we continued to observe an average downward movement of water, while in Aiyura, on average, water tended to move upward towards the rooting zone. Although these observations help to explain the total yield differences between the two sites, they do not explain the reduction in yield over time. There was no detectable decline in nitrate release or in soil organic matter since monitoring commenced in mid-2008. No nitrate was observed at 100 cm depth. Climatic conditions during the duration of the trial are also an unlikely cause for the yield decline under back-to-back SP cropping. No differences in the outbreak of pests or diseases were observed since the trials commences. It is possible that declines in nutrients other than nitrogen limit yield under continuous cropping. In the light of observations made in the scoping study, a declining sulphur concentration may have limited yield, particularly in Simbu.

7.4.5 Conclusion

The mother trials did not demonstrate soil fertility decline over a 3-year SP cropping cycle in the situations evaluated. This was different to our expectations based on farmer observations and scoping study data. The capacity of the system to sustain yields for 3 years is attributed to the sites selected which had all been under prolonged fallow and achieved a reasonably high level of fertility restoration. In this situation a 3 year trial period was insufficient to show nutrient rundown. However, the data do show that despite the highest cumulative yield for back-to-back SP, individual yields per season declined. A considerable limitation of the data collected was its tremendous variability. This made it impossible to delineate and assess the effect of sub-factors such as tillage method and type of fallow on SP productivity. In hindsight and a lesson learnt for future activities was, to reduce treatment numbers and increase plot size and number of replicates. It is unclear how much of the variability is due to the section of cultivars. Given the advance and push to release pathogen tested SP not only into commercial farms, but also to subsistence farms, future work should use pathogen tested material not only to reduce variability but also to foresee large scale adoption of pathogen tested planting material. It was also impossible to assess the impact on yield data of theft of harvestable product. Furthermore, yield theft is likely to have resulted in a diminution of treatment differences as theft was more likely from successful treatments.

A rudimentary partial nutrient balance showed quite clearly that even with local varieties of low yield, nutrient extraction will exceed nutrient accumulation during a fallow phase. More accurate nutrient balance studies should be undertaken. How much the nutrient balance can be closed depends on yield and type and length of fallow species. There is little doubt given the population increase in relation to available land, mineral fertiliser will eventually be required. However, this will not happen in the short-term given the near subsistence existence of a considerable proportion of the Highlands population, and the current complete absence of mineral fertiliser use on SP. Planted fallows with fast growing nutrient accumulators such as Tithonia diversifolia (Wild Mexican Sunflower), will be one option for the near future but insufficient information is currently available as to which fallow species are suitable and more importantly, adoptable.

The nutrient omission trial was of limited value due to the unrealistic fertiliser application rates needed in the small pots, the high variability arising from the use of sweetpotato as a test species, and the short length of time vines were grown for. Future nutrition work should only use pot trials as a soil fertility evaluation tool to refine treatment selection, with the substantive evaluation of sweetpotato nutrition undertaken in field trials. Furthermore, our data on plant tissue nutrient levels also do not match with the threshold levels commonly used (O'Sullivan et al., 1997). This may be due to cultivar differences or differences in vine age or stage of growth, but for practical purposes it will be more important how plant tissue nutrient levels, or tuber nutrient levels, relate to tuber yield over and above the productivity of vine biomass.

The nutrient omission trials suggest Mo as a growth-limiting factor; this has been reported for vegetables (Hughes, *pers. comm.*) and should be further investigated since Mo deficiency can also affect legume productivity, e.g. peanut.

Our data on water movement and potential leaching of nutrients indicated that, despite the high rainfall in the highlands, there is limited leaching. On the Humept in Aiyura and similar soils in the Eastern Highland, the subsoil is very dense with very low hydraulic conductivities. On these soils lateral movement of water above the subsoil could cause leaching; this lateral movement is not identifiable using the experiment conformation employed here, and its importance may need to be investigated further.

7.5 The baby trials

Following the indications that composted mounds are most suitable and at least partially able to stabilise SP yields, and in a move to encourage farmers not to burn, famer field schools were held to educate farmers in soil and soil fertility management. This activity was originally assigned to the Lutheran Development Service but later reallocated to a leading farmer, and experienced farm trainer, Joseph Kuru.

7.5.1 Methodology

The farmer field schools comprised of two parts; a 3-5 day training program at the start of a SP season and a follow-up at the end of the SP season. Having more regular training sessions was not needed as the SP crop is planted and then pretty much left on its own until it is ready for the first tuber harvest, i.e. our activities were aligned to farmer practise. The relatively short training period also reduced the pressure on farmers to be present at more regular meeting which is more common when conducting farmer field schools. Such intense and regular training are often an impediment for farmer attendance. The training program also included other aspects of SP production than soil and soil fertility management. Add-on topics included preparation of planting material, method of planting as well as pest and disease management. The add-on activities were based on farmers' demands and ensured good attendance. During the training program farmers were encouraged to try their own ideas; 'farmer as researcher'. Of particular interest were suggestions to use Tephrosia not only as a N-fixing legume in the compost but also because its pesticide properties help to control weevils. Tephrosia is also used catch fish as the toxin in the leaves numb the fish making them easier to catch. It is not known how effective this pest management method works, but farmers were indeed interested.

Joseph Kuru used the term 'NPK-mix' to encourage farmers to use composts. Farmers are well aware of mineral fertiliser and understand that they contain N-P-K; the new approach used by Joseph was to call a mix of plant species an NPK-mix to show farmers that some plant species are effective organic fertilisers. The term NPK-mix is now very well known in the Highlands.

Not all sites where 'before-season' training was conducted had a post-season follow-up. On some sites yield data from the baby trials was collected, but the data had limited reliability.

7.5.2 Summary of farmer field schools conducted

Most of the farmer field schools were planned and conducted by Joseph Kuru. He also trained CDA (Community Development Agency) officers from Kundiawa as trainers who then ran their own training programs. According to Joseph's records, a total of just under 6000 farmers were trained. The median group size was 22 farmers but at times the training was combined with showing demonstrations plots at large events of several hundred attendees such as NARI field days or NGA gatherings.

Joseph's records are probably an overestimation, but it is fair to state that the total number of farmers who were exposed to the soil fertility training is in the order of thousands.

7.5.3 On-farm experimentation

Limited results were obtained from the 'farmer as researcher' trials. Figure 13 shows that yields could be increased using small composted mounds on some sites but had little effect on other sites. The benefits of using composted mounds were most likely affected by soil fertility status but probably were also due to pest and disease control. Given the variable results it is imperative that the entry point for soil fertility work focusses on low fertile sites where addition of fertiliser will have a fast impact; i.e. not high fertility sites like the ones we selected for our mother trials which had been several years under fallow prior to cropping.

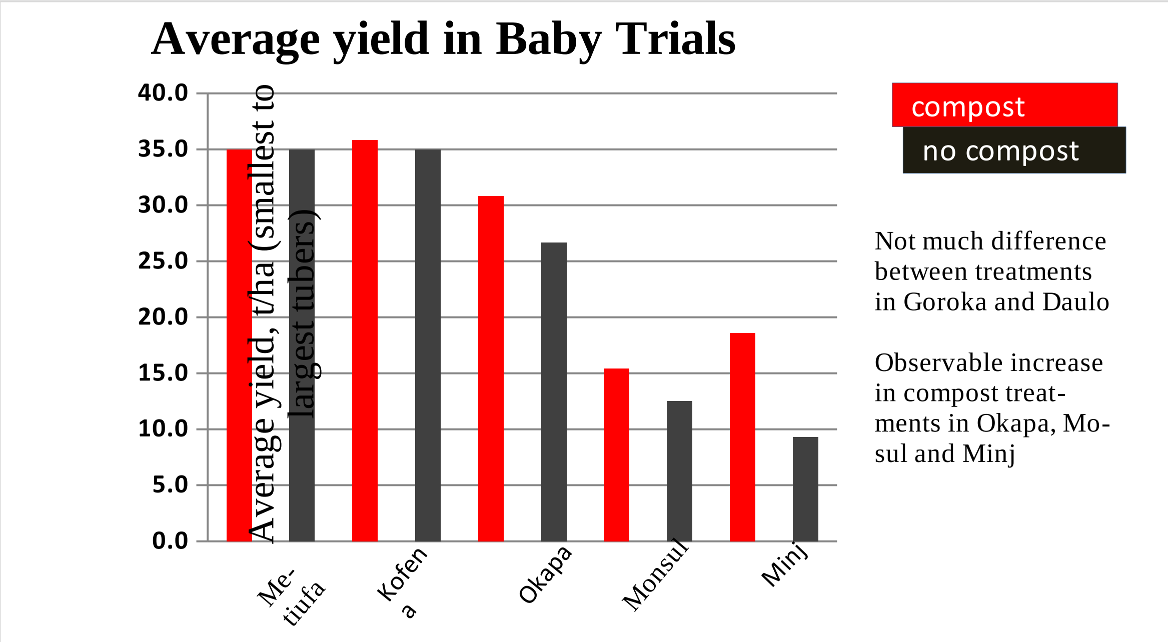


Figure 13. Effect of compost use on yield at two different 5 different sites.

Table 17. Effect of composted mounds on pest damage and nematode counts. (Pest damage scoring: 1: very low (0-5 %), 3: Low (6-10%), 5: Intermediate (10-40%), 7: High (40-70%), 9: Very High (70-100%)

Site	Treatment	Average Weevil damage	Average Nematode damage	Average Nematode count
Metiufa	Compost	5	5	679
	Nil	7	5	534
Kofena	Compost	1	1	679
	Nil	1	1	352
Okapa	Compost	1	1	137
	Nil	1	1	95
Monsul	Compost	5	3	285
	Nil	3	3	280
Minj	Compost	1	3	274
	Nil	5	3	151

Despite farmers' assurance that composting had a beneficial effect on weevil infestation, our observations were variable (). The effect of weevil damage was unclear with more weevil damage on some sites and less on others. Composting appeared to have no impact on nematode damage but increased number of nematodes, indicating that root lesion nematodes are not increased by composting with a possibility of composting having a beneficial effect on free living nematodes.

7.5.4 Conclusion

A large number of farmers were trained on soil and soil fertility management. There was considerable farmer interest in this training, possibly due to an awareness of yield reductions from continuous cropping and reduced fallowing. Although it was evident during farm visits by project staff, and reports by Joseph Kuru, that farmers engage in practise change away from burning towards composting, reliable data could not be collected in this regard. For future research activities more emphasis should be placed on on-farm, farmer managed trials with research staff conducting thorough monitoring to assess the main drivers of SP yield formation as a consequence of farmers' own actions. Process study trials, such as those attempted at Aiyura and Tambul station and the Kondiu High School will remain difficult to conduct, due to problems with site security and the reliability and consistency of trial management and data collection.

8 Impacts

The project was conducted over almost 6 years and most impacts for the future are largely from lessons learnt in how to improve the management of research projects in PNG in light of the difficulties experienced. The main impact was in capacity building and in awareness creation of soil fertility management not only for NARI, but for the Highland farmers in general. Scientific impacts were limited due to the many problems faced in implementing a rather complex project. Difficulties in collecting reliable data were also exacerbated by a large staff-turnover within NARI with project leadership and project staff changing on several occasions.

8.1 Scientific impacts – now and in 5 years

The scientific impact is more about learning how to conduct soil science research in the future and how problems can be managed and minimised. Reliability of data collection and adhering to the agreed protocol, together with security problems were the main issues. It is unlikely that security will improve in the near future and site selection will remain a problem. Reliability in running a project effectively will require minimising the complexity of the experimental design. This, however, will reduce the potential for researchers to engage in detail process studies where high-tech equipment is needed. For future work it will be important to use methods that are simple, reliable and easy to maintain. High tech equipment, such as the data loggers we used, should be avoided.

From an agronomic perspective, SP is amongst the most difficult crops to investigate. Even simple parameters such as tuber yield are difficult to assess, in particular if farmer practice is followed using sequential harvesting, and if the yields of different sized tubers have to be assessed There is a need to simplify or standardise a perceived simple task such has obtaining tuber yields.

The fertiliser rate and omission trial was probably fundamentally flawed as regards its relevance to the yield of SP tubers. Published nutrient threshold levels did not correspond to the plant tissue levels observed even under excessive fertiliser application rates. The longer term scientific impact is awareness that we are still very unsure how crop nutrition relates to tuber production. It is noteworthy that using nutrient ratios (DRIS), rather than absolute concentrations to diagnose nutrient limitations on tuber production, proved to be successful in the original scoping study (Bailey et al., 2009). A further confounding difficulty is the tremendous variability in SP varieties used in the highlands. Future projects can manage this variability by using pathogen tested planting material which is projected to be adopted on a large scale in PNG.

Results indicate that vertical leaching of nutrients may not be important despite the high rainfall in the Highlands, particularly on soils with very impermeable subsoils. Lateral movement of nutrients may be more important, which also raises the question of interference from nutrients on other parts of slopes adjacent to the areas where plot trials are conducted.

Nevertheless it is clear from the various experimental results that supply of N, K and S into the farming system will be necessary to lengthen cropping periods, and to support increased yields. There are various indications that micronutrient deficiency may be limiting yield, with the potential for Mo deficiency to be limiting legume performance in particular.

8.2 Capacity impacts – now and in 5 years

Prior to the project, NARI had very little expertise in soils science and no projects on soil related problems. In the course of the projects this has changed and NARI staff gained substantial expertise and awareness on the importance of soil fertility. This is particularly important for the advent of pathogen tested SP material where increased yields will result in substantially increased nutrient removal rates.

Training was an integral part of this project. Two NARI staff (Issac Taraken and William Sirabis) attended a 2-month training program at UQ where they participated in our undergraduate courses and conducted simple glass house trials, e.g. on effect of growth medium temperature on SP growth. This has helped Issac to enter a Masters program in NZ, and William is now earmarked for post graduate training at UQ. At UQ, a PhD student is now engaged in a project to assess the effect of temperature and nitrogen on tuber formation. This new research project is a direct consequence of the work done by Issac and our assessment that nutritional thresholds based on plant tissue analysis on vines grown for just a few weeks has little relevance to SP productivity in terms of tuber yield.

The main part of the capacity building component was via on-the-job training through regular visits by Australian project staff to work alongside the NARI team in conducting the field trials. This exposed all of NARI Aiyura to soil science as well as students from Vudal, Goroka and UniTech in Lae, some of whom did internships at NARI Aiyura. Emphasis was always placed on low cost methods to achieve a scientific outcome. Simple examples are using coffee grinders instead of laboratory grade grinders to prepare plant samples, or building a drying oven out of household heaters instead of using an expensive dehydrator. The impact clearly was an increasing understanding that much can be achieved on a limited budget.

8.3 Community impacts – now and in 5 years

The famer field schools were our main means to raise awareness soil fertility constraints on SP to Highlands Farmers. Although the total number of farmers trained (i.e. almost 6000) is probably an overestimate, a substantial number of farmers have been exposed to the importance of soil management in relation to sweetpotato productivity.

The initial entry point for the famer field schools was delivery to the farmers free of charge, and meals and some travel expenses were covered. The level of investment was scaled back as the farmer field schools progressed. Towards the end of the project farmers paid to travel to the venues and also paid for their meals. This clearly shows that famers appreciated the training and were willing to contribute financially. A follow-up survey on a small number of farmers also shows that framers are interested in more training and that yield improvements in SP occurred following training in the use of composted mounds.

During the project our lead trainer, Joseph Kuru, was paid out of project funds. A business model was discussed for Joseph to help him develop a business as a consultant providing training and advice to farmers as a paid service. This did not happen in the course of the project but offers an opportunity for Joseph or others to earn money since famers are evidently willing to pay for training. A move away from free services provision to paid services provision may need to be taken more seriously as it is a common observation that farmers become complacent when depending on free services. This is more pronounced when famers are being paid for the use of their fields as experimental sites. This has not happened in our project, but is a common practise which often captures farmers who are only interested in the income and not in the objectives of the project.

The selection of the Simbu site was partly due to its potential for disseminating results into villages as students graduate from High school and return home. When the trial was set up, a very motivated teacher from Kondiu was in charge of the field trials. He ensured that students were included in the trials and were available in action learning while the project team conducted field work. However there were two problems: (1) everything came to a standstill during school holidays, and (2) the trial had to be terminated when the teacher left to work elsewhere. This clearly shows that a 'champion' is needed on-site to ensure progress and reliability. Nevertheless, engagement of education providers in PNG as research participants may provide an effective means of outreach with the potential for long-term beneficial impacts.

8.3.1 Economic impacts

During the life of the project, the population in the PNG Highlands increased by almost 1 million people. Following this project, and part of an SRA, the original survey that was conducted prior to this project was repeated. A main finding was that length of fallows has rapidly decreased. PNG has limited options for expansion of agricultural lands and increased productivity of staple food must come from land use intensification. Although it is not possible to assess the economic impact at this time, awareness of the need to intensify land use is paramount for economic growth.

8.3.2 Social impacts

It is not possible to assess the economic impact at this time.

8.3.3 Environmental impacts

An integral part of practice change supported by this project was reduction in burning as part of land preparation, and use of fallow biomass as an organic fertiliser, mulch or compost. A reduction in burning will reduce greenhouse gas emissions and residue retention will also reduce soil erosion; both have long term environmental benefits though they are impossible to quantify at this time.

8.4 Communication and dissemination activities

A number of community outreach activities ranging from poster presentations at field days to radio interviews were conducted throughout the project. The list below summarises these activities:

- NARI in house seminars:
    - April 9, 2010, Issac Taraken, Soil nutrient cycling: C, N, S and P
    - April 23, 2010, Debbie Kapal, The prospects of green manuring in PNG agriculture
    - June 4, 2010, William Sirabis, Importance of soil analysis for soil fertility maintenance in PNG agriculture
    - June 18, 2010, Debbie Kapal, Soil fertility management options in sweet potato based cropping systems in the highlands of PNG
- Poster display at Kondiu High School (Soil Fertility Management in the PNG highlands Soil Fertility Management in the PNG highlands for Sweet Potato for Sweet Potato-based Cropping Systems based Cropping Systems).
- John S Bailey (2007) Students undergo training. NARI Nius, Number 4, Volume 10, Oct-Dec 2007, page 11.
- Issac Taraken and Kai Lali (2010) Radio interviews/talk show on soil fertility and challenges of climate change in the PNG highlands. National Newspaper, February 2010
- Issac Taraken (2008) Students trained in Soil Sampling. NARI Nius, Number 3, Volume 11, Jul-Sep 2008, page 3.
- Radio interviews/talk show on soil fertility and challenges of climate change in the PNG highlands conducted and aired by PNG National Broadcasting Commission (NBC) Eastern Highlands, NBC Simbu, NBC Enga, Ipili FM Porgera, NBC Mendi (Southern Highlands), and NBC Western Highlands between January 11 and 19 2010

- William Sirabis and Debbie Kapal (2009) A Bumper Harvest. National Newspaper Weekender edition 1st May 2009, page 8.
- Participation by first group of farmers with Joseph at the NARI Innovation Show in Lae on May 5 2009. Related newspaper article 'Agricultural Innovation Show a Success' was published in the National Newspaper's NARI supplement on May 14 2009
- Participation of second group of farmers with Joseph Kuru at the NARI Innovation Show in Lae on May 5 2010
- Debbie Kapal and William Sirabis (2009) Innovative Sweet Potato Farmers Addressing Soil Fertility Problems in the Highlands. Poster presentation at NARI Innovations Day, 5th May 2009
- Farmer field day hosted by Joseph and farmers at Banz on December 15 2009. Related story/article was published in the Post Courier newspaper on December 18 2009.
- Taraken, I., Bailey, J.S. and Kirchhof, G. Macro and micro-nutrient limitations affecting sweet potato growth on soils from different parts of the PNG highlands. Poster presentation at 'Science and Technology Conference, University of Goroko, 21-24th July 2008
- Issac Taraken and John S Bailey (2007) Soil fertility management project initiated. NARI Nius, Number 4, Volume 10, 0ct-Dec 2007, page 4.
- Poster display for public awareness, Sep 2009 (Major Nutrient Deficiencies in Sweet Potato Gardens Surveyed in Enga, WHP, Simbu & EHP in 2005).
- NARI workshop 21 – 25 March 2011. NARI workshop: Soil fertility management options in sweet potato based cropping systems in the highlands of PNG (15 sessions)

9 Conclusions and recommendations

9.1 Conclusions

Critical nutrient thresholds determined for sweetpotato (SP) vines after just 5 weeks growth are unlikely to be of value when assessing crop nutrient status in relation to tuber production. Even in terms of vegetative production, it is unclear how much value these published (O'Sullivan et al., 1997) threshold values have, given the tremendous variability in SP vines and in their mineral nutrient requirements (Coleman, E. *pers. comm.*). Field-based rather than pot-based assessments are best when investigating relationships between soil nutrients, tissue nutrient concentrations and SP tuber yields. In this regard, data from the Scoping Study were successfully used to link both soil exchangeable K concentration and vine leaf K concentration with tuber yield (Walter et al., 2011). Furthermore, it was found that the critical soil Colwell P concentration necessary to achieve optimum P concentrations in SP vine leaves was four times greater for volcanic soils (102 mg P/kg) than for non-volcanic ones (24 mg P/kg) (Kirchhof et al., 2008). Even more importantly though, DRIS (Diagnosis and Recommendation Integrated System) tissue nutrient norms (based on critical nutrient ratios), were developed which are capable of accurately evaluating the N, P, K and S sufficiency status of mature SP crops in terms of tuber production potential (Ramakrishna et al., 2009; Bailey et al., 2009).

We offer an elaboration to the recommendation from the review team at the final project meeting that there is a need for further investment in field trials to investigate macronutrient limitations on SP production potential. We consider that there is already sufficient evidence that macronutrient supply does limit production potential, and that future work should not dwell overly on the specific response to nutrient application (traditional rate trials), but should largely focus on non-mineral fertilizer options for supplying these nutrients. Traditional rate trials will only be of value in determining the limits of response to inputs. A more substantial challenge is how to manage soil fertility under field conditions in a near-subsistence setting. That being said, there may be scope for mineral fertilizer to supply micronutrients, and there is a need for field trials to investigate limitations in SP production from deficiencies in micronutrients such as Mo, Ni, Mn, B or Zn.

In the series of 'mother' trials, there was no clear evidence of soil fertility decline on sites that had been under fallow for several years. Indeed on one such site, back-to-back SP crops gave the highest cumulative tuber yield even though yields per season were lower than for systems incorporating a fallow phase. It is assumed therefore that soil fertility decline is only relevant on sites where cropping occurs over longer periods, albeit the term 'longer' cannot be quantified at this stage.

Nutrient removal in harvested tubers and nutrient build-up during a fallow phase depends on tuber yield, fallow type and fallow length. Nitrogen supply seems to be least influenced by these factors owing to the low N-content of tubers and hence low level of N removal in tubers. In our trials, high yielding grasses or low yielding legume fallows were able to offset this N removal, at least where yields were low and more typical of those obtained by farmers in the Highlands. However, K and S removal can easily exceed the rates of accumulation in soil during fallow periods, and moreover appear to be site-specific. Volcanic soils tend to have considerably lower K-reserves than non-volcanic soils (Walter et al., 2011; Bailey et al., 2008b). Mobilisation of K from mineral reserves is likely to occur for some considerable time, but if the K-pool collapses, use of mineral fertiliser may be necessary. However, there are valid arguments against using fertilisers for managing K nutrition. They are expensive and difficult to transport to remote garden areas. What's more, they are readily leached out of soil when heavy rainfall occurs. A more appropriate strategy would be to use certain fallow species with the capacity to pump nutrients up from the subsoil into the rooting zone (Walter et al., 2011; Hartemink, 2003; Bailey et al., 2008b). Sulphur is mobile in the soil and accumulation is also only really possible through nutrient pumps which draw S up from subsoil reserves into the rooting zone. Sulphur is also lost when fallow vegetation is burned and when SP vines are removed from gardens to feed animals. Curtailing these practices will also help to prevent S becoming limiting to SP production. Preliminary results show large differences in ability of different fallow species to accumulate nutrients, but little is known about which species would be best suited for adoption by farmers.

Leaching of nutrient as a cause of nutrient decline was one of our main hypothesis. However, we were unable to confirm this loss mechanism. Lateral movement and subsequent loss of nutrients is more likely to occur than the vertical movement we investigated. Lateral movement is most likely to occur on sloping lands with low permeability subsoils; with the results of this project demonstrating that such situations may be common in the Highlands.

The mother trial or process study was plagued with equipment failure, mishaps and inadequate capacity to maintain a complex trial setup. This meant that few usable results were obtained from the process study. Future detailed process studies will need to be conceived in a manner where detailed instrumental sampling can be undertaken across a limited time period, permitting site security to be well maintained. A key aspect will be either to achieve greater site security, or farmer/community engagement to a level at which theft from the experimental plots can be controlled.

The famer field schools were very well received and from farmer visits we gauged considerable success in terms of increased farmer interest in soil management and in trying out their own ideas, i.e. the famer as researcher model. The potential for non-replicated trials on individual farmer’s fields (with replication provided by working with multiple farmers) as a research tool should be further evaluated.

9.2 Recommendations

The scoping study which preceded this project provided excellent background data in terms of farmer perception of soil fertility decline, land use and soil and crop biophysical assessments. Part of this survey was repeated as a component of the SRA SMCN/2012/016 (Review of research needs on resource management and crop protection for sweetpotato based cropping systems in PNG). A comparison of the two sets of survey results indicated a further reduction in the length of fallow periods, indicative of an intensification in land use that will inevitably lead to exhaustion of soil nutrient reserves. This depletion of soil nutrients will be further compounded if the projected uptake of high yielding pathogen tested material by Highland’s farmers occurs. At present, subsistence farmers do not use mineral fertilizer on sweetpotato, albeit there may be residual fertiliser nutrients remaining in their sweetpotato gardens following other crops, such as cash crops, where mineral fertiliser is used.

To satisfy the increased demand for sweetpotato as the population increases, more land needs to be used for agriculture or else land must be managed more intensively. The former is a limited option due to the topography of the terrain, though it is not clear how much expansion actually occurs. Published data from Mike Bourke indicate little increase in land under cropping, but anecdotal evidence suggests expansion is occurring. Intensification is a preferred option as it also reduces the problem of land clearing. In the absence of mineral fertiliser use, intensification is only likely to be possible where fast growing nutrient accumulator fallow species are utilised. Candidate species are *Tithonia diversifolia* and *Piper aduncum*, but insufficient information is currently available to enable specific fallow species to be recommended or to advise farmers concerning the best method of short fallow for soil fertility maintenance.

We recommend that work continues on the assessment of land use changes and cropping patterns through the use of low altitude aerial photography. This will not only quantify land use but also give background data for the assessment of land use changes and project impact on land use. Investigation to select suitable fallow species will also be needed and tested with famers, possibly in conjunction with continuing work on small composted mounds. This will directly link with the research on pest and disease control using composted material to reduce pathogen infection and insect pests such as weevil.

Following our lessons learnt we also recommend that process studies must be kept simple and should be located only at the Aiyura station or other secure sites (NB even in the Tambul station the data logger was stolen). Where possible, data collection should be in focused periods, rather than continuous. More emphasis should be placed on working with farmers and promoting the 'famer as researcher' model. Given that it will be close to impossible to implement replicated trials in a single farmers' field, we would enguage a multiple farmer / community approach.

Given the promotion and expected update of pathogen tested planting material, these new activities should only use the pathogen resistant varieties. This should help to reduce sweetpotato cultivar/variety induced variability, it add value by providing an assessment of the longevity of pathogen tested material

10 References

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11 Appendixes

11.1 Appendix 1: